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How Technology Transfer is Understood in the “Field”? Towards a Systemic Analysis of Technology Transfer in Estonian Biotechnology Sector

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Abstract

Existing discussion on technology transfer and commercialization tends to predominantly follow a linear view where the knowledge itself, transfer processes and socio-economic impacts are treated in a relatively simplistic manner. This article seeks to contribute to filling in these gaps in understanding the exploitation and diffusion of knowledge generated through university-industry linkages by analyzing the case of the biotechnology sector in Estonia. Based on successful cases of technology transfer we try to describe and explain the development trajectories of academic business ventures from a more systemic perspective. We show that both the process of technology transfer and its impact are dependent on the local contextual conditions (supply, demand, and policy). In the case of biotechnology in Estonia, technology transfer seems to take place in a state-subsidized model and through processes and logics that are to a large extent in opposition to both the expectation of the linear view and also of the biotechnology sector.

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Abstract

Existing discussion on technology transfer and commercialization tends to predominantly follow a linear view where the knowledge itself, transfer processes and socio-economic impacts are treated in a relatively simplistic manner. This article seeks to contribute to filling in these gaps in understanding the exploitation and diffusion of knowledge generated through university-industry linkages by analyzing the case of the biotechnology sector in Estonia. Based on successful cases of technology transfer we try to describe and explain the development trajectories of academic business ventures from a more systemic perspective. We show that both the process of technology transfer and its impact are dependent on the local contextual conditions (supply, demand, and policy). In the case of biotechnology in Estonia, technology transfer seems to take place in a state-subsidized model and through processes and logics that are to a large extent in opposition to both the expectation of the linear view and also of the biotechnology sector.

Keywords: technology-transfer processes, diffusion of knowledge, university-industry-state relations, **entrepreneurial perceptions, biotechnology**

1. Introduction

Even though both national and regional innovation systems are foreseen to embody the complementarity between knowledge-generation and knowledge-exploitation sub-systems (Cooke 2004), in practice not only public polices, but also most empirical studies are overwhelmingly engaged with the issue of knowledge generation and not that of exploitation or diffusion (Brown and Mason 2014).

Respectively, policymakers tend to foresee a rather idealized role for universities in the regional context and innovation systems in general. In line with the emergence of the "*academic entrepreneurship*" (Etzkowitz and Leydesdorff 2000), the role and expectations of research-intensive organizations have been magnified as these are assumed to be the key actors for increasing the socio-economic impact of R&D and knowledge-creation activities (cf. Ooms et al. 2015; Uyarra 2010). Even though the original concept highlights a feedback-based and interactive innovation model incorporating linear and reverse linear modes of innovation (Etzkowitz 2003, 112-113; also Kline and Rosenberg 1986), the current debates on knowledge transfer tend to remain stuck in the one-sided linear view (Rothaermel et al. 2007).

Thus, the existing discussions seem to be structured by static categories and limited analytical perspectives, underemphasizing the potentially varied impacts of technology transfer and the dynamism of the entrepreneurial processes in it (for a literature overview, see here, e.g., Mustar et al. 2006). As a result, many crucial dynamic factors are overlooked in technology-transfer discussions, i.e. the demand-side issues, like geography of economic activities, synergies derived from existing value-chains and supporting industries and their absorptive capacities (Porter 2000a, 2000b), patterns of technological change also determining knowledge-transfer channels, types of interactions and the nature of possible complementarities between universities and industries (Tödtling et al. 2006; also Dosi et al. 2006; Bonaccorsi 2008) and the wider institutional context-specific factors (see here Mowery 2011; Bozeman 2000; Bozeman et al. 2014; also Polt et al. 2001a, 2001b).

This article seeks to contribute to filling in these gaps in understanding the exploitation and diffusion of knowledge generated through university-industry linkages by analyzing the case of the biotechnology sector in Estonia from a more systemic perspective. On the one hand, the selection of biotechnology as a case study is in line with the overall focus of the sector on research valorization for commercial as well as for industrial purposes (Powell et al. 2007). On the other hand, the developments of the sector in Estonia are considered an excellent case to illustrate how the local context can be crucial in affecting the real potential for technology-diffusion processes. The Estonian innovation system and its policies have largely followed the linear approach to innovation (see Havas et al. 2015; also Izsak et al. 2014), presumably the most suitable for the science-based sector, such as biotechnology (see Pavitt 1984). While on the basis of advancements in science, Estonia is considered "*a poster child for successful transition to Western-style science*", together with its strengths in material, biomedical and environmental technologies (*Nature* 2009a, 2009b), the developments at the level of business models and industry in general have been regarded as modest at best (e.g. Kirs 2016; Suurna 2011; also EuropaBio and Venture Valuation 2009 for CEE experience in general).

This study aims to shed more light on technology transfer as a dynamic model with an emphasis on the diffusion processes. Through this lens we hope to uncover the challenges related to university-industry-state interaction from a more systemic perspective. In doing this, the article aims to answer the following research questions: *How can the technology-transfer and -development trajectories of the business ventures that have grown out of a public R&D system be described and explained? What could be identified as systemic problems to be solved by public policies in order to enhance technology diffusion and its socio-economic relevance?*

The study is structured as follows. In Section 2 we highlight some of the main failures of the linear perspective on technology transfer and discuss the alternative systemic perspective. Section 3 describes the research methodology and the sample of selected cases. The results of the analysis are presented in Section 4. The wider discussion, together with possible policy and research implications, is provided in the concluding section.

2. From linear to systemic understanding of technology transfer

The term "*technology transfer*" refers to "*organizational and institutional interactions involving some form of technology-related exchange*" (see Bozeman 2000, 629; also Polt et al. 2001a, 2001b). One can argue that the current discussion on interactions between science and business (and policies) relies too much on the linear innovation model and especially on its implicit *assumption that outcomes of science are eventually relatively easily understandable* and mostly in the form of codified bodies of knowledge routinely used by the industry for innovation processes (see here Etzkowitz and Leydesdorff 2000; Etzkowitz 2003; Kline and Rosenberg 1986). As a result, the main focus of theoretical and normative discussions is on how to make the objects "*robust*" enough to get them out the door (Doganova 2013, 449). This also leads to sometimes excessive attention given to the role of different (intermediary) actors involved in the technology-transfer processes. These somewhat simplified assumptions tend to determine how the (economic) benefits of (publicly funded) basic research are measured and evaluated. In this paper, we follow a more dynamic and evolutionary perspective of technology transfer, recognizing the diversity of the bodies of knowledge (e.g. tacit *vs*. codified, STI- *vs*. DUI-based), patterns of technology transfer (e.g. codified *vs*. human capital-based) and of triggers and barriers of technology transfer (supply and demand and also policy-related factors). This perspective highlights several limitations of the linear model proposing also alternative lenses for studying technology transfer. In doing so, the technology-transfer model is approached as a dynamic multi-step process.

2.1. The limits of the linear perspectives

First, the predominant technology-transfer models presume that the *object of transfer is predetermined* at the very beginning of the process. In this vain, however, the real underpinnings (supply and demand context) for the technology transfer have received considerably less attention. From the evolutionary perspective, Nelson (2012, 679) has argued that quantitative indicators of patents, licenses and start-ups capture only some parts, the later stages, of the innovation model. Bonaccorsi (2007) has shown that the arguably weaker performance (in terms of patents, licenses, start-ups) of European research as a whole stems from the more systemic elements of the innovation systems. In the overall picture, Europe is characterized by a lower specialization in the areas that can be regarded as general-purpose technologies with a variety of diffusion pathways and applications. Such institutionalist perspectives have opened up wider avenues to explain the different context-specific factors to be involved in the model of technology transfer. As derived from the European (failed) attempt to emulate the US rhetoric and practice, the debate has emerged emphasizing that the real functioning of policies and policy instruments to support the science and industry interface is strongly affected by the structural differences in innovation systems and by the broader orientation of the institutional framework of each economy (Mowery 2011; Powell et al. 2007; Bonaccorsi 2007).

In other words, from the evolutionary perspective the focus should be on basic research capabilities, not only in terms of supporting advancements in the fundamental science, but also in terms of having open access to research results as well as domestic capabilities good enough to break into the international networks "*where the new technologies are being hatched*" (Nelson 2005, 25; Nelson 2006; Powell et al. 2007, 141; also Heller 2008). At the same time, in the context of transition and developing countries, the reliance on foreign-made technologies and the respective capability-building is stated to be more important in economic terms than reliance on the indigenous R&D efforts (Tiits et al. 2015, 315; in general, also Perez and Soete 1988, 462-463).

Second, there is a *wide spectrum of patterns that remain under-emphasized* by the prevalent approach of technology transfer, especially concerning feedback paths within the development processes, including experimentation processes of the science and industry interface, but also the (informal) information and R&D collaboration these interactions are facilitating (Kline and Rosenberg 1986; Nelson 2012; Doganova 2013). More specifically, these patterns of technology transfer concern university-industry interaction in terms of new ideas, labour mobility, influx of students (read stock of useful information and skills), conferences, spread of new instrumentation and methodologies, access to networks of experts and information, complex technological problem-solving, practical help and assistance, etc., which are essential in the adoption of basic research results and its specification and spread to the needs of the industry but are not so easily distinguishable (see Salter and Martin 2001; Roessner 1993; also Bekkers and Bodas Freitas 2008: 1840; Trippl and Tödtling 2006; Cohen et al. 2002).

Third, in the linear model, most of the emphasis has been put on the commercialization of valuable discoveries as an objective in itself, reflected also in the high importance of indicators and activities belonging to the "*harder*" end of the spectrum of knowledge transfer (the so-called "*out-the-door*" criterion via spin-off firm formation, patenting and licensing) (Bozeman et al. 2014; Philpott et al. 2011; de Jong et al. 2016). This practice has been reinforced by the decrease in the stable and direct state funding of research (Etzkowitz et al. 2000; Heinz et al. 2009; Coccia and Rolfo 2008) affecting academic freedom and incentives regarding research and technology transfer (Philpott et al. 2011, 162, 167; de Jong et al. 2016; Slaughter and Rhoades 2004; Karo 2010; Powell et al. 2007; D'Este and Perkmann 2011, 316; Colyvas 2007; Bozeman et al. 2013).

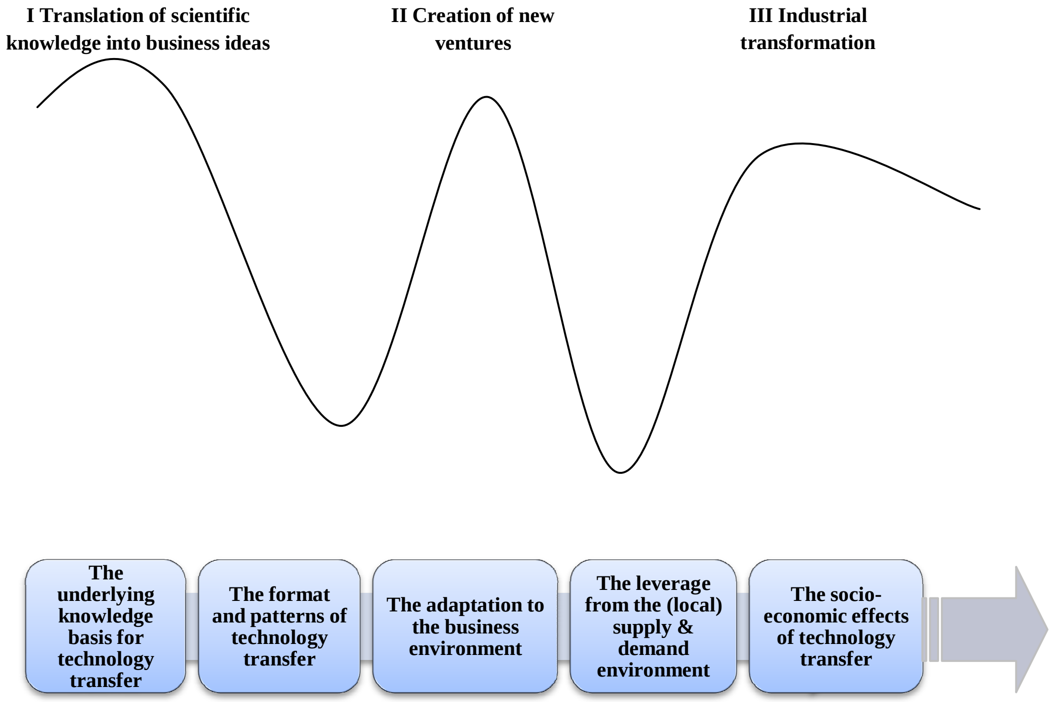
Thus, from the more systemic perspective, Bozeman et al. (2014) call for paying complementary attention to the issue of *public-value criterion and impacts* (*Was it beneficial*?) in contrast to solely focusing on the economic benefits (*Was the technology transferred?*) of technology transfer. In other words, the prevalent focus on the so-called "*gold standard*" for the assessment of market impact/economic development captures only microeconomic impacts (firm sales and profitability) but remains more than limited regarding systemic achievements and sustainability issues (Bozeman et al. 2014, 6). As such, it has been claimed that the narrow focus on the commercialization of R&D results fails to tackle more systematic problems of industrial transformations, especially in transition economies (Tiits et al. 2015, 314).

Fourth, and shifting the analysis from scientific to entrepreneurial issues, the linear model has *assumed a rather straightforward process of technology transfer*. From the time-line perspective, attention has been given to the early stages of a venture development focusing on how ventures grow out of a scientific sphere and what kind of role firm-specific resources, institutional linkages as well as business models play in the creation of economic value (for a literature overview, see Mustar et al. 2006). In this vein, a number of different models and typologies to capture the essence of academic ventures have been established (for a comparison, see the stage model of academic spin-off creation by Ndonzuau et al. 2002; cf. academic spin-offs as explorative intermediaries by Doganova 2013). Djokovic and Souitaris (2008, 237, 242) argue that there is a scope for further research regarding the post-formation product development and growth of spin-off companies with a specific focus on the issues related to technology regimes and lifecycles as well as market factors (tendencies towards segmentation, the effectiveness of patents, the importance of complementary assets), etc.

From a more evolutionary perspective, it is argued that the debate has been stuck in static categories, underestimating a dynamic view of the entrepreneurial processes (Mustar et al. 2006; Druilhe and Garnsey 2004, 282-283). From the perspective of adaptation processes to the business environment, some of the key aspects to be focused upon include: a variety of distinct sets of competencies needed in the early stages of venture development with an emphasis on the key aspects, such as the discovery and identification of commercial opportunity, the role of individual characteristics to take a championing role in the process and the capabilities for resource acquisition (e.g. Rasmussen et al. 2014); the importance of social networks and the specificity of network ties (being strong, but few and informal between academia and industry, see Johansson et al. 2005, or the advantages for start-ups to be related to networks rich in bridging ties, see Scholten et al. 2015); the different business orientations of ventures (from technical consultancy, sales and research services toward more product-oriented business as time evolves) (e.g. Druilhe and Garnsey 2004); the critical factors relevant (financial resources primarily) to change the developmental trajectories and growth of ventures (Wright et al. 2004).

In contrast to the resource-based view, where competitive advantage is dependent on the strategies for exploiting existing firm-specific assets (see above), the concept on dynamic capabilities exemplifies the importance of high-performance routines inherent in the company to be able to adapt (also via reconfiguration of external linkages) to the changing environmental conditions (Teece et al. 1997). So, the question is not whether and how the academic ventures are embedded into interactions of knowledge networks, but the notion that these relationships are highly dynamic as well. For example, Perez and Sanchez (2003) demonstrated how in Spanish university spin-offs technology transfer and networking with the university (as parent) decreased over time (in contrast to the practice prevalent among corporate spin-offs), while the relationships with customers increased. This tendency was accompanied by the change of more frequent polarization towards technology than to market in the business orientations. The previous could be also considered to be one of the peculiarities of the biotechnology sector, where research and early exploitation tend to be highly regionalized, but in development and distribution and marketing we speak about a highly globalized industrial sphere (Kaiser and Prange 2003).

Figure 1. From a linear to a multi-step approach for technology transfer



Source: Authors, the conceptual idea derived from Polt et al. 2001a, 9 and Meslin et al. 2013.

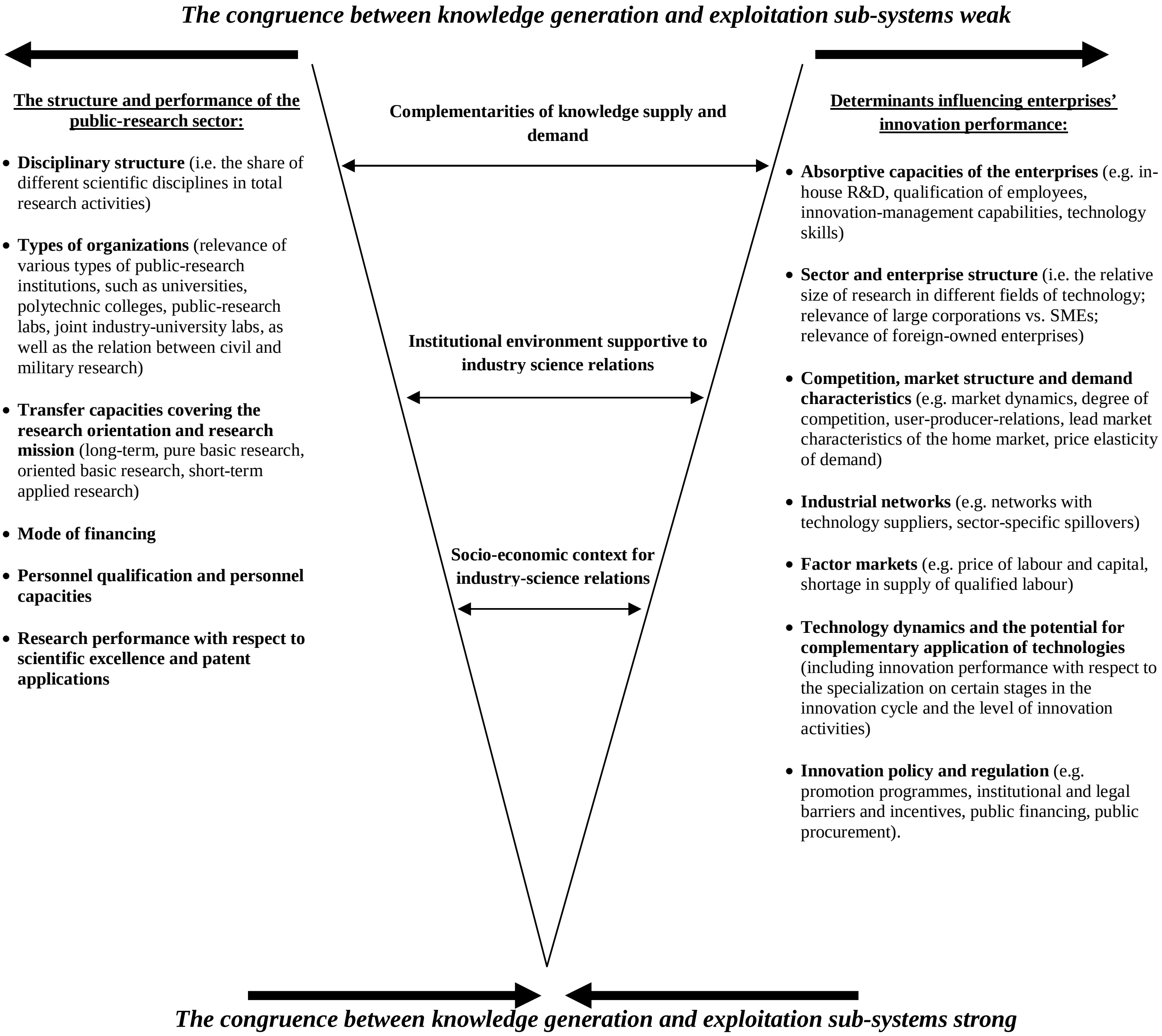
In sum, it can be argued that the current academic debate on technology transfer does not cover the whole picture of possible stages, impacts and outcomes, especially as the real impacts can be unexpected (Bozeman et al. 2014, 4-5). In other words, we can also think of technology transfer as a dynamic multi-stage process. For the main stages and factors affecting the technology transfer with focuses on diffusion processes as highlighted in this article, see Figure 1.

2.2. A systemic framework of technology transfer

When speaking about innovation-driving activities in an economy, "*the flow of knowledge*" (whether in a direct or indirect format) constitutes one of the key aspects, but most certainly not the only one (Mazzucato 2013, 52; also Polt et al. 2001a). In other words, the demand side issues, including those of identifying "*the company-specific conditions that must be present to allow spending on R&D to positively affect growth*", have been largely neglected in the current policy as well as empirical studies (Mazzucato 2013, 44; Dosi et al. 2006 on Europe particularly). In this vein, the technology transfer as such should not be seen as an independent process to be tackled, but as one that intervenes into the wider issues of complementarities between supply and demand environments as well as the respective knowledge transfer and absorptive capacities (Bozeman 2000; Polt et al. 2001b). Importantly, the further away universities and economic sectors have specialized, the more effort, time and investments does it take to induce technology transfer and especially increase the impact of transferred technology (see also Figure 2).

Figure 2 provides a more detailed picture in understanding the congruence between knowledge generation and exploitation sub-systems and its structural underpinnings in different (possible) categories. In the context of this article, essentially we speak about an explanatory framework to understand and explain the contextual factors in the regional context and innovation systems in general that ultimately (may) affect technology transfer and diffusion processes as well as the dynamics and trajectories involved from the wider institutional and socio-economic perspectives.

Figure 2. A systemic perspective on technology-transfer complementarities



Source: Authors, in relying on Polt et al. 2001a; Cooke 2004; also Brown and Mason 2014; Lember et al. 2015.

So, while the overall emphasis in technology-transfer policies has been very strongly on the development of framework conditions (public-promotion programmes, intermediary infrastructures, legislation and regulation and institutional settings) in the European countries in particular, one has to consider, firstly, the different modes possible for characterizing the industry-science interface (from a simple linear model to a chain-link model), the different effects these interactions may have, not only on the national but also on the cross-country level, and time-lags in the effects of interactions, but also of different framework conditions to occur

(Martin and Tang 2007; Polt et al. 2001a). Even though the demand-side issues have been opened up in more detail in Polt et al. (2001a), they have failed to keep the attention on these particular issues while speaking about technology transfer (for a comparison, see Polt et al. 2001b). In spite of the acknowledgement of the systemic problems, the reactions to those have originated from the market-failure rationale (Polt et al. 2001b, 254). Hence in this study, the policy-making mechanism in place is argued to have a wider impact on the functioning of the system, where severe problems of cooperation and collaboration between different stakeholders are detected, reflecting in this way also the general innovation climate in the context of which the development of (high) technology should take place. The latter is particularly important in the framework of the argument according to which networking is less hampered by the initial density of trust and ties at the micro level and rather by the difficulties of "*scaling up*", e.g. bringing together different stakeholders of the process (Evans 1995; also Radosevic 2009).

Secondly, the framework conditions are not only specific to certain national and international industry networks, but also to different economic sectors and fields of technology (referring here to the different nature of linkages that will vary, along with market conditions, demand characteristics but also technology characteristics; Polt et al. 2001a). This also means that the dependence on the foreign value-chains and the reliance on the trends as dictated by the wider economic structures and relationships, make it rather difficult to change the nation-state specific specializations by the local policy-makers (see Karo et al. 2014). In the transition countries, the problem can be further amplified by the overwhelmingly poor level of capacities and demand of local traditional industries, which, if overlooked, considerably affects whether and to what extent the expected synergies are to be created by general-purpose technologies in real terms (see here Suurna 2011, 102; in general also Dosi et al. 2006).

In sum, one can say that the underlying ground for future developments is derived from cooperative and co-creative relationships between academia-industry and policy-makers, amplifying the need for context-specific innovation policies and systems (see also Bozeman 2000), the realization of which, however, is extremely challenging the further away an economy is from the technological frontier.

3. Research methods employed and the sample of the cases selected

In contrast to the prevalent research strategies, this article aims to open up the transformation of academic research into economic value from an alternative perspective, focusing on the entrepreneurial side (creation and evolvement of new ventures) of technology transfer.

In order to track the developments, a purposeful qualitative sample of successful cases in the Estonian biotechnology sector was compiled (for detailed information, see Table 1). The sample covers two different modes of commercialization of public-sector technology: (1) "*inventor-entrepreneurs*" – university employees who actively seek to commercialize their own inventions;

and (2) "*surrogate-entrepreneurs*" – those who acquire rights to the university-developed technology (Radosevic 1995). The term "*successful*" refers here not only to the enterprises with a history of significant sales and revenues, but also to the essence of the technological advancement that they are supposed to carry, in other words, the development of alternative or complementary technologies rather than the pure substitution of the existing products/services (Audretsch and Link 2012). As the information available to the wider public on the solutions, technologies, methods, etc. grown out of the Estonian R&D system is neither systematized nor comprehensive, the study is explorative by nature. Nevertheless, the selection of the cases is representative in terms of the major research groups and enterprises active in the sector.

The empirical analysis relies upon the triangulation of different research methods for the compilation of data. As a first step, extensive desk research was conducted to detect the cases relevant for the study and application of the criteria as described above. For this purpose, different sources of information available to the public were explored in depth, including the media coverage and business reports on financial activities in the Estonian Commercial Register (*Äriregister*). As a second step, interviews with representatives of business ventures who combined both managing and R&D-related positions were carried out. Altogether, 12 biotechnology enterprises (including representatives of all major enterprise groups and competence centres in Estonia) were interviewed and to these, eight interviews with representatives of different biotechnology research groups in Estonia in the field were added (previous studies have shown that there are altogether 43 biotechnology research groups active in Estonia, see Karo et al. 2014). The latter are highly relevant due to the great fusion between the academic and business spheres of the field in Estonia (see also Suurna 2011; Karo et al. 2014).

Table 1. Sample of the (successful) cases selected

The case	Type of venture	Initiative for TT	Underlying knowledge basis for TT	The format of TT	The key aspects/barriers in adaptation to business environment	The leverage from the (local) demand environment	The leverage from the (local) public policy measures	The socio-economic effects of TT (the key aspects only)
Prosyntest AS/ Cambrex Tallinn AS (1989)	Became a spin-off of TUT in the mid-2000s	A group of academics	International R&D project + local analytical capabilities	Informal (staff)	Lack of marketing capabilities; high volatility due to service provision	No; dependent on international value-chains. Acquired by MNC in 2008.	No influence whatsoever on the side of EAS. A partner in CC for Cancer Research.	Establishment of production facilities; important employer in the field of org. chem; a practical site.
TBD-Biodiscovery OÜ (2006)	Spin-off of UT	Academics + entrepreneurs + US venture capitalists	Local analytical capabilities	Informal (staff)	Lack of marketing capabilities; high volatility due to service provision	No; dependent on international value-chains mainly.	EAS support measures important (during the period of economic downturn, but also for the opening of the new R&D lines). Strong influence by the Tartu Biotechnology Park. A founding member of CC on Health Technologies.	Important employer in the field of org. chem; with high export revenues; a practical site.
Asper Biotech Group (1998)	Spin-off of UT and Estonian Biocentre	An academic entrepreneur + an entrepreneur+ US venture capitalists	*Postdoc* period in the US + international R&D project	Technology + informal	Diversification of portfolio; now looking more strongly towards the local market	Partially yes: public demand by the reimbursement policy of the Estonian Health Insurance Fund; also international R&D projects.	EAS – supportive role in the foundation, but also in R&D projects (e.g. developing a separate oncology portfolio). A partner in CC on Health Technologies.	Development of DNA tests and services and the respective technology (e.g. DNA chip for breast cancer); one of the biggest employers in the field of biotech; a practical site.
Quattromed AS / Quattromed HTI Laborid OÜ (1999)*	Quattromed AS is a spin-off of UT	An academic entrepreneur + representatives of clinics – "co-working" area	*Postdoc* period in the US	Technology + informal	Business model combining the technology development with innovation in service provision; plus providing a full package of services in the field; CEO's championing role	Yes, benefitted the most from public demand created by the reimbursement policy of the Estonian Health Insurance Fund. Acquired by MNC in 2013.	EAS + SPINNO programmes supportive to the transfer decision and period); influence on R&D projects restricted (the company's resources have been sufficient). A partner in CC for Cancer Research.	Development and provision of new types of diagnostic services (relying on molecular biology) to the Estonian medical sector; the biggest employer in the field of biotech; a practical site.
Quattromed AS / Icosagen Group (1999)**	Quattromed AS is a spin-off of UT	An academic entrepreneur		Technology + informal	Serving a specific niche in the local as well as international value chains	Limited: international R&D projects mainly.	EAS support relevant for R&D projects; in terms of foundation, see also the previous case. Cooperation to CC on Health Technologies.	Platform technologies important for development of new drugs, including Ebola; important employer in the field of biotech; a practical site.
FITBiotech OYj Plc Estonia (1995)***	Contractual relationship	Contract research to a Finnish company	Joint publication	Informal (specific capa-bilities)	-	If at all, the quality/cost ratio.	Funding from TEKES.	Experience & well-paid work; development of DNA vaccine for HIV; the collaboration led to the foundation of a subsidiary in Estonia.
Protobios Group (2003)	Some have been formed legally as spin-offs of TUT	Contract research to the US partner; few academic entrepreneurs + venture capitalists	Working experience from the US	Informal (staff)	Risk management	Due to authorizations required, restriction to the local market (limited in size) not reasonable; reliance on "exit strategy".	Substantive influence on the side of EAS R&D grant allocations – a significant degree of allocations converged into the hands of this Group. A founding member of CC for Cancer Research.	A range of potential new technologies, products and services in process; the group is an important employer in the field of biotech.
Self-diagnostics	Students' spin-off of	Classmates + an academic	Local + increasingly	Informal (staff) +	Gathering experience but also additional funding via	No; increasingly affected by the German development	Substantive influence on the side of EAS since foundation of the	Development of easy-to-use medical devices to detect

OÜ (2008)	UT	entrepreneur as a co-owner/consultant	international (IZI) capabilities and capacities	contracts to R&D institutions	secondary activities, such as sales of last-generation DNA-tests	context; also international R&D projects. Established a subsidiary in Germany.	company. Significant financial support by the Development Bank of Saxony, AufbauBank SAB.	infectious diseases at the Point-of-Care.
CC of Food and Fermenta-tion Technologies & Bioexpert OÜ (1991)	(Students') spin-off of TUT	Academic entrepreneurs + "underground" initiative by students (Bioexpert)	CCFFT – highest impact from the international R&D projects	Informal (staff)	CCFFT – international orientation and making money	In strategic terms, international R&D projects; certain degree of stability from the local (mature-food) industry.	Not dependent on EAS support. The support has been used to build up the infrastructure and train the staff, but the exploitation of it has been covered by the sales from its own activity. Bioexpert – a founding member of CCFFT.	CCFFT: upgrading local mature-food industry; graduate school; contribution to creation of new good-quality jobs (over 60).
Probiotic bacteria Lactobacillus fermentum ME-3 (1995, 2001)	Commercia lization of IP	Classical case of TT together with patenting and licence agreements	International R&D project	Patent	Active engagement of UT department for TT	Limited: exclusive licence held by one company in the dairy industry (some other strains granted to the Bio-CC of Healthy Dairy Products); the direction on food supplements relying on international R&D cooperation.	EAS support has served as an important basis for building up the specific manufacturing capability and realizing the pilot project. See also the previous column. The regulative environment in the EU not supportive: EFSA has not approved any claims on probiotics.	Upgrading local mature-food industry; development of a wide range of product lines in functional food.

Note: *,**, *** all related to one single academic entrepreneur in essence.

Clarification of abbreviations: TT – technology transfer; TUT – Tallinn University of Technology; UT – University of Tartu; CC – Competence Centre; EAS – Enterprise Estonia; IZI – Fraunhofer Institute for Cell Therapy and Immunology; EFSA – European Food Safety Authority.

Source: Authors.

4. Technology-diffusion patterns in the Estonian biotechnology sector

Following Table 1, we next outline the main factors influencing the patterns of technology transfer and diffusion in the Estonian biotechnology sector.

4.1. The underlying basis for technology transfer initiatives

The underlying logic of the Estonian R&D strategy relies strongly on supply-based innovation development. In reality, however, we managed to map only few successful spin-off companies and ready-made solutions that mark the case of a linear technology-transfer model from academia to the market. Also, it can be argued that, if at all, then the foundation of spin-off companies should be seen primarily as personal pet projects (driven by personal aspirations, goals and interests) of key persons behind the companies (in some cases also the realization of aspirations for the sake of local development) rather than examples of a long-term strategic direction of "*entrepreneurial university*" and its implementation. Thus, there is a strong dependence between the technology-transfer processes and the single entrepreneurial academics to detect the market potential of their research activities.

Perhaps somewhat surprisingly from the linear perspective, but as expected from the systemic-evolutionary perspective, the domestic technology-transfer processes with a significant economic impact have converged around the research themes and groups with high-level research excellence. In other words, an important prerequisite for knowledge transfer relies on a very good level of basic science, which, in turn, is seen by the interviewees to be strongly dependent on decent permanent public funding rather than anything else (including a project-based funding system). Hereby, it is important to note that the entrepreneurs active in the field see the university's role foremost as a provider of general knowledge and human capital (graduates), but also as a platform for testing new ideas and solutions. As was admitted by one of the respondents:

> *The primary task of a university is, after all, to educate students and to do research; science and innovation issues are on the table, largely, because of getting additional funding. It is not a secret. The government should understand how and why different actors in the R&D system prioritize their activities. If it is believed that the entrepreneurship gets promoted via giving money to universities, then too bad indeed.*

The representatives of the entrepreneurial side highlighted that partnerships with universities primarily imply the existence of certain (basic) capabilities/technologies to be there, whereas the case studies revealed some restrictions here, as well. The latter also explains somewhat why the cooperation and joint projects of the foreign partners (on the side of local entrepreneurs) have attained increasing importance.

In other words, the knowledge basis for technology transfer has been very strongly related to the developments taking place in the international arena. Estonian involvement in joint research projects as well as in contract research has been based on speed- and cost-advantages supported by sufficient (not necessarily world-leading) professional competence and relying on global companies. Taking part in scientific conferences and international R&D cooperation projects (FP7, Horizon 2020) has not only served as a breeding ground for developing networks and contacts, but essentially also provided significant public funding, necessary for basic R&D and business activities. Hence, essentially the aforementioned policy measures have helped the spin-off companies to survive outside the R&D system, while developing their technology niches. It is also important to note that more often than not the key persons' specific knowledge and experience as derived from their stay in the international environment (for studies, work experience) have opened up certain so-to-say "*windows of opportunities*" to be realized in Estonia.

4.2. The main patterns for the technology transfer and adaptation of the technology to the business sector

Even though a large share of the biotechnology enterprises in Estonia has in one way or another grown out of the public R&D system, contrary to the expectations of the linear model, the foundations of the new ventures are almost never based on the transfer of codified knowledge. Almost all interviewees emphasized people (academic entrepreneurs, qualified personnel and qualified graduates) with their specific knowledge and skills (who also act as shareholders and/or (senior) R&D consultants in the spin-off companies) over more codified bodies of knowledge: "*Education only. Know-how and qualification of the staff.*" Thus, the ties between the academic and business networks are highly personal and constant (in the style of "*You can always make a phone call*"), which is a further deviation from the linear and biotech-based models in more developed countries.

It has been rather exceptional for the codified knowledge grown out of universities to be passed on to the external parties of the R&D system in a neat format of technological solutions, IP, etc. The knowledge-transfer processes in this format can only be exemplified in some particular fields of molecular-diagnostics technologies and/or methods and of food technologies. As a rule, the business models of the field are not built around the codified knowledge as derived from universities; to the contrary, the latter play rather a supportive role in the majority of cases. As the domestic market dominated by micro enterprises (established by academics) is in the phase of infancy, there is no clear demand for codified IP, either, and the foreign market is too complex and difficult to enter, given the existing research capabilities. The specialization of the biotechnology sector in the provision of specific services rather than the development of original products further reduces the importance of codified knowledge.

Further, several interviewees pointed out that a large share of biotechnology developments (including the development of technology-based products) grown out of the R&D system tends to remain stuck in the development phase. One of the major problems here is seen in the different routines prevalent in the industrial and academic spheres (e.g. what kind of information is needed to guarantee the credibility of product functioning *vs*. to publish an article). The departure of scientists from universities is, however, a rather exceptional practice. Hence, the role of the universities remains to provide "*shelter*" for the respective research groups until a commercial niche has been found or failure or exit from the system has taken place, whereas the key scientists tend to rely on the university salary and position/reputation in parallel and later on. Crucially, the success in technology transfer concerns mostly those cases where a decoupling from the public R&D system took place soon after the start, further confirming the dynamic view of transfer processes. As a rule, the alignment of organizational culture and routines to those appropriate in the business sector presume the involvement of a particular person ("*a champion*") with a business background and a visionary in the development processes. Also, the technology basis transferred to the enterprises is developed further while relying on their in-house capabilities (including the development of new-generation technologies/techniques), whereas the expansion of a portfolio is strongly affected by the (foreign) customer needs, but also by participation in different (international) R&D projects (FP7, Horizon 2020, EAS, etc.). The latter explains to a certain extent the low interest to remain engaged in interaction and cooperation with the relevant (domestic) research groups in universities, as well.

The dominance of the so-called "*contract research*"-based business models makes specific demand conditions – the presence of the first "*core customer*" in particular – a top factor when starting the commercialization activities. These contracts are not only important in order to process possible specific niche R&D developments as well as to invest in business processes in general, but also because of the access gained to (global) value chains as such. In this light, it has become increasingly common that business models are built upon the separation of service delivery and development activities (including the IP corresponding to it). The transfer of IP that results from the development work of the independent legal entities is argued to be more appropriate to meet the investors' interests. There are also companies that have managed to establish a specific status of a certain service-delivery niche in value chains, the protection by patents of which is not considered either cost-efficient or necessary.[1]

Even though the biotechnology sector is very science-intensive, the entrepreneurs' perceptions of the *formal image of being a spin-off company* remain controversial. There are companies which prefer to define themselves through their internal research capabilities (e.g. being active in publishing). There are also companies that have built their competitive advantage upon the affiliation to an R&D institution. As such, the image of being a spin-off is seen as ambivalent, referring either to the strong analytical capabilities as derived from a public R&D system or to the possible problems in relation to the potential information leakage, the actual R&D

[1] According to the Estonian R&D database ETIS, the number of patent applications by Estonian scientists registered in the US was 159 in total by December 2013, whereas in the case of 22% the economic rights were authorized to the Estonian researchers and universities; in the case of 18% rights were authorized to the Estonian enterprises (mainly companies founded by academics and the majority of those in the field of biotechnology), and in the rest of the cases (60%) to the foreign institutions or companies registered abroad (Karo et al. 2014).

competence (especially due to the involvement of students) and the complexities of sharing the IP belonging to a university. Based on the information gathered during the interviews, one can question why the format of spin-offs has received overwhelming attention in policy rhetoric. In reality, the formalization of business ventures as spin-offs does not seem to have much to do with technology-transfer processes by nature, but with the reflection on the wider institutional environment – i.e. providing feasibility for applying for different state support measures on university-industry cooperation (e.g. procurement of infrastructure, in particular).

4.3. The leverage from the (local) demand environment

In general, the demand for biotechnology transfer from university to industry in Estonia has been weak and indirect at best. Several interviewees admitted that too high expectations have been set for competing at the international market in line with the overall export-orientation strategy of Estonia. At once, these companies were forced to face the extreme volatility prevalent and struggling with insufficient marketing capabilities necessary in the area of service provision, whereas the local potential and somewhat more secure environment remained underexploited. Today, a certain change in the mindset has occurred, yet actions still lag behind.

A rather exceptional example in the system is the *development of food technologies* (e.g. nutrition testing/development, fermentation), especially by the Competence Centre of Food and Fermentation Technologies (CCFFT), which, paradoxically, is one of the most mature and stable industries with a very long time-frame. The transmission of codified knowledge has played a greater role here than in other sectors as well, because it provides a more stable basis for long-term contracts and specializations (enabling the definition of an array of applications more specifically, etc.). Nevertheless, the underlying basis for these developments has emerged from the combined impact of the cooperation projects, together with international partners and with the food industry locally. Also, the relatively strict EU regulations regarding the food sector have been a crucial demand-creating element.

The other application areas of biotechnology have not enjoyed such leverage from the local demand, which is also why the main focus of the sectors is still on the phase of development, but also on building up the local demand environment. In *pharmaceuticals*-related activities, the business models are strongly oriented towards an "*exit-strategy*" and the respective specializations aligned to the industry's investment interests and possible future prospects as set by the global actors (e.g. research on the cancer treatment). Due to the high regulative environment in the field, it was admitted by one of the interviewees that: "*There is no point to carry through the development activities just for the sake of the Estonian market. Often this is also impossible due to high standardization in common everywhere*." There are also application areas in Estonia (e.g. oil-shale energy/chemistry), where industrial demand is so specific that it cannot be met by the universities locally any more (which either have not been able to acquire the capacities relevant or to maintain these).

In sum, the leverage effect of public-sector demand has varied. Even though *public hospitals* could be seen as important potential users for biotechnology applications, according to the interviewees, their real impact on the technology-transfer processes has been limited. On the one hand, hospitals are important partners for the businesses and universities as sites to carry out clinical trials (even though here the cooperation more often relies on the enthusiasm of single persons than on general organizational practices, especially as R&D as such is not prioritized in the current public-funding mechanism). On the other hand, the clinical material the local hospitals can offer is not found representative enough by the enterprises, in particular if they are dependent on global value chains. However, the Estonian context is occasionally considered to be attractive for drug development projects. As one of the interviewees commented on the situation:

> *For the sake of the Estonian public sector one has to admit that the bureaucracy involved is not so extensive as in other (larger) European countries. In Estonia, the processing of paper work (especially as everything has to go through the Estonian Agency of Medicines) is considerably simpler and faster. The primary reason that brought the development phase/project in question to Estonia is the speed of processing. It took half a year, while elsewhere two years is the ultimate maximum*.

The other important national actor to affect the local demand is the *Health Insurance Fund of Estonia*, whose activity via inclusion of certain procedures, methods, etc. to the list of reimbursed services in particular has enabled several new technologies to spread. It was admitted by the interviewees that many start-up companies, especially in the early stage of development activities, are dependent on whether their activity can be included in the service list of the Health Insurance Fund. As the latter is in turn affected by the lobby of medical associations, their awareness in technological advancements but also their demonstration of cost-efficiency to hospitals and clinics is what matters in real terms. Nevertheless, the primary orientation of the Health Insurance Fund has been the provision of a more stable market and conditions for the diffusion of ready-made solutions. Here, the criticism can be concluded by the statement of an interviewee: "*The tax money should stay in the country and not serve the interest of development companies [multinationals]*." An overly patient-based funding system with a focus on treatment and not on prevention and health behaviour may be an additional factor inhibiting business and technology development. One can assume that if the initiatives are not leveraged by the public health-care system, the commercialization on the end market does not have many perspectives, as has been shown by the several cases of genetic-disease testing solutions.

4.4. The leverage from the (local) public policy measures

The share of those companies that have managed to cover the development costs by means of their own activities (including sales and other secondary activities) is rather exceptional but not non-existent. To a significant extent, the knowledge transfer in the field of biotechnology has been funded by the public sector (EAS, as well as investments from foreign development banks, etc.). The evaluation of the impact of these measures seem to be rather complex.

On the one hand, and according to the interviewees, it is rather difficult to attract the private investors' interest to support technology-transfer processes (no specific product/service often available). The state support (that is presumably more "*patient*" and appropriate for riskier R&D projects, see here also Mazzucato 2013) is found to be relevant (at least during economic downturns). In contrast to the theoretical assumptions, the Estonian R&D support system is neither found to be patient enough nor appropriate to support more complex capacity-development efforts of the private sector. As a result, some promising spin-off companies have already moved into the hands of foreign capital, especially in the stage of more intensive applied research and development activities needed. As admitted by interviewees:

> *In fact, there is no demand for the development activities anywhere and from anybody other than on the side of a state … Our logic for survival relies upon service delivery and not on the development activities. Even more, it is the contract research that essentially enables the development of these capacities that are to be commercialized later.*

> *EAS was set up to support enterprises, but today the product development has to be funded by the enterprises themselves. As the support rate for R&D projects is higher, most of the enterprises are engaged with R&D activities, whereas outputs in terms of real products are yet to be shown.*

On the other hand, *subsidy-dependency* can be detected in certain particular cases as well (see here Kirs 2016). One of the interviewees commented on the problem rather vividly:

> *There has been too much 'easy' (grant) money. The main and only presumption for distributing the (state) money should be that capitalists risk their own money (self-financing) … There is a big difference in how private capital acts: R&D projects to pay salaries for researchers or to earn money … Looking back, one can say that a lot of money is received by the 'weak' projects and/or by the projects with limited economic impacts. At the same time, there was a strong need for the money to get distributed … It is also true that this money has made a relatively good political lobby. Essentially, the same R&D projects have received support for the first, second and third time – just making a bit of change in project titles, but dealing with the same thing …*

In light of previous, the capacities to successfully obtain state grants often prevent the companies from making a decisive development in the R&D, and many "*are jumping standing still*". Hence, the vicious circle for start-up companies tends to occur: there is a need to get rid of the academic routines and to hire people with a business background (marketing, sales), for which, however, the companies are too small, so they do not dare to take any risks.

In this context, it is more than relevant to note that the successful cases of biotechnology transfer in Estonia go back to the late 1990s and early 2000s, whereas the policy support structures were still in their infancy. The success of these cases could be rather seen as a result of several important factors working in combination as follows: the "*real*" demand for the research activities (via the inclusion of medical doctors as consultants into the research groups); the institutionalization of demand in the Estonian health-care system by the Health Insurance Fund;

the foundation of companies in the field as a natural reaction by some of the key academics; the emergence of specific financial instruments (Innovation Fund, the predecessor of the EAS) and national support mechanisms/programmes (SPINNO); the inclusion of people with entrepreneurial background; and the existence of competent university graduates. The early funding allocated via the Innovation Fund had a somewhat different format: it embodied both a grant to the R&D institution to cover the time for transfer (including the wages for researchers) and a loan to the corporation to cover the development expenses, but it acted as an enforcement mechanism to speed up the processes at the same time. The grant allocation was also bound to the participation in international R&D projects to validate the credibility of the undertakings as well as of the staff.

From more current instruments, the measure to support joint public-private *competence centres* (CCs) has had a relatively unique impact on the R&D system. In principle, this is the only measure which has tried to affect R&D activities and the respective transfer processes not only through financial means, but focusing on establishing and constantly developing new organizational routines, networks, capabilities. For example, from our interviews it emerged that the more successful CCs have evolved over time from more scientist-driven entities towards more co-productive organizations where, if needed for technology transfer, the role of academics has been reduced in favour of more development- and marketing-oriented staff. At the same time, the less successful organizations have remained closer to the academic focuses both in organizational structure and strategies.

In sum, due to the impact of policy instruments such as the CC measure, a significant part of academia-business cooperation takes place not directly between universities and businesses, but in other "*entities*" that bring together interested businesses in the field. Yet, as these firms are the co-owners of these centres, the potential for wider technology transfer and socio-economic impacts has remained restricted due to competitive pressures and interests. Further, these CCs have a somewhat different role to play in different application areas of biotechnology. Hence, and primarily depending on the stage of the application area in terms of the technology cycle, the CCs are perceived differently by the side of entrepreneurs: from useful partners in R&D collaboration (the case of more complex and mature sectors, such as food) to a comfortable (financial) leverage (the case of early-stage and market-seeking areas, such as cancer research). In principle, in the context of Estonian biotechnology transfer processes, we have to talk about "*a closed circle of friends*", or corporatist business-academia networks, where informal cooperation prevails. In addition, it is argued that the development work carried out in CCs would not be sustainable without public support. As there is an increasingly strong pressure on the CCs to become economically independent of the state, the very essence of CCs comes under threat to a certain degree, as well. After all, the only plausible alternatives to increasing the share of commercialization are seen either in a certain simplification of R&D activities (service-orientation) or moving backwards in value chains.

4.5. Explaining technology transfer and diffusion patterns

The specific characteristics affecting patterns of technology transfer in Estonia as described above are deeply embedded in the wider socio-institutional environment: starting from a mismatch between the capabilities of public R&D institutions and industrial needs and ending with public policies ill-equipped to leverage the potential initiatives in question.

Firstly, the R&D policy has driven the universities to concentrate on the production of scientific results that are internationally competitive (the so-called "*1% publishing*") and has neglected the market feedback (e.g. it is often impossible to publish the results from applied research, yet there are no counterbalancing mechanisms taking non-published research results into account in research evaluation or funding decisions).

Secondly, the Estonian economy as a whole is arguably still in an investment phase, whereas the development is driven mainly by process innovation (deployment of new machinery and other ready-made solutions and not R&D) and whereas the demand for R&D is concentrated in the hands of an extremely small group of local enterprises (around 60-70 companies cover 90% of the private investments in R&D) (see, e.g., Mürk and Kalvet 2015; Roolaht et al. 2015). The biotechnology sector serves as a special case here: a magnified expansion of the industry in quantitative terms is argued to have gone hand in hand with the change in business models, whereas the orientation taken on risk-management strategies rather than R&D-intensive synergies and specializations tends to prevail (Kirs 2016; Suurna 2011). Reliance upon short-term returns and specialization in activities creating lower added value could be taken as the reflection on the general business environment prevalent in Estonia. In other words, today's policy rhetoric and measures are limited by nature to create wider synergies from technology-transfer processes, especially as the private sector does not have the absorption capacities as assumed in the context from which the policies have been transferred.

Finally, one can argue that the current R&D system has concentrated most on the development of basic research capabilities and according to the international academic peer-review principles, whereas the dimension that could exercise the socio-economic relevance in a systemic way is still missing. In other words, relying on the interviews one cannot have the impression that the public sector has tried to "*get to the bottom*" when articulating demand for R&D. Firstly, the incapability to set the long-term priorities together with the specific programmes, etc. have led to the situations where the academics by themselves state what is needed or what they could do in some extreme cases. As one of the major problems here, the lack of relevant policy-making and implementation capacities is highlighted (in particular those related to the impacts assessments). In the light of the previous, secondly, the majority of public-sector contracts are oriented on the services of consultation, monitoring and implementation assessments, whereas the linkage to the technological advancements remains vague, and hence also the wider socio-economic affect of the technology transfer is not in the spotlight. The attempts, limited though, to induce or spread new technologies and applications via the formulation of public need have not had the result as expected, either, mainly due to the limited involvement of end-users to the processes, in turn leaving the development to "*sit on the shelf*".

As a result, the main problem in the Estonian innovation system is not the gap of complementarities in knowledge generation and exploitation sub-systems, but that is has become wider and more fundamental.

5. Conclusion

As seen from the Estonian case study, the policy rhetoric and ambition of the linear technology-transfer model do not match the actual impact even in the field of biotechnology. The treatment of technology-transfer processes reflects rather narrow-minded thinking and a belief that this is an ultimate end in itself. We can say that focusing on such a narrow goal and re-enforcing this through policy and academic rhetoric does not fully support transfer processes, either, that are dependent on the local context or achieving a larger socio-economic impact of R&D. Here the other aspects in relation to the sector-specific policies should be highlighted, as well, especially those that concern the stage in the technology lifecycle and the appropriability of the demand context (including the existence of local supporting industries as well as the nature of value chains in the industry).

In the case of Estonia, the prevailing pattern of technology transfer in the field of biotechnology is strongly tacit, informal and supplementary, rather than direct by nature. It is true that several success stories (e.g. diagnostic services relying on molecular biology; commercialization of IP on ME-3 bacteria) also fit very neatly into the format of a classic linear model. Nevertheless, these are rather exceptional and not prevalent cases. Paradoxically, these cases were initiated when technology transfer policy support structures were largely non-existing, at least from the perspective of the linear model. Still, they have benefited from both good scientific capabilities and the fact that specific technologies have been more appropriate for commercialization. In most recent cases, these conditions have been much less supportive, and the majority of cases have come to be dependent on the state support mechanisms.

The prevailing rhetoric of technology transfer leaves untouched the routines of R&D institutions and industry. The universities follow strategies based on basic research logics and are unwilling to shift voluntarily towards corporate and public demand with different constraints (shorter time frames, more unstable financing) requiring changes in basic routines and strategies of universities. Basically, the R&D institutions are not motivated to get involved in the experimental and applied R&D activities. The willingness by the private sector to finance the aforementioned initiatives directly or indirectly via the EAS measure of R&D grants is, however, more than limited. As was shown in the case studies, the success stories of technology transfer require both academic and business-related leverage from international financial and knowledge networks.

Essentially, the paradox presented here is a classic outcome of the "*copying paradox*", where the belief in single almighty policy measures takes the focus away from broader contextual issues. As shown above, the focus on the formal technology transfer of codified bodies of knowledge has established rhetorics and expectations that are difficult to fulfil within the existing academic and business context. This has, in turn, created a vicious cycle of subsidy-dependence. In essence, it does not matter much from which end of the technology-transfer processes – either from the end of the academia and wider commercialization of its research results (supply-based orientation) or from the end of entrepreneurial discovery processes, assumingly forming a stronger basis for socio-economic need (demand-based orientation) – policy-makers have sought to initiate changes.

The key challenge is still to find the synergies between these two and developing specializations complementary to both. The artificial support to magnify the university-business cooperation has not only considerable limits in bridging the gap of capabilities in the two sectors in real terms, but even more may result in shared disappointment in the prevailing rhetoric as such. As a result, some of the more promising cases of technology transfer have in fact been transferred abroad prior to their expected impact being achieved. Still, the measure of competence centres has been somewhat exceptional here as it has been the only long-term effort to build and sustain new organizational routines and capabilities explicitly regarding technology transfer. Nevertheless, the wider socio-economic relevance of CCs in technology transfer is still a challenge; economical turnouts remain to be enjoyed by a small circle of founding companies and partners. Overall, the socio-economic relevance of technology transfer depends on how policy-makers are able to take into account the sector specific aspects of technology transfer, even if these are informal and tacit by nature.

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