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The Dynamics of Technology Transfer in a Catching-up Innovation System: Empirical Evidence and Actor Perceptions from the Estonian Biotechnology Sector

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Abstract

Based on the case studies from the Estonian biotechnology sector, we explore the development trajectories of academic business ventures in a country where the formal and linear model of technology transfer and commercialization have been at the core of the innovation policy, but the exploitation and diffusion of knowledge generated through formal university-industry linkages has remained limited. We show that even in the area of biotechnology, where one could expect this model of technology transfer to be most visible, the model is not functioning in practice and the policy has had limited impact. The more systemic evolutionary approach to innovation and knowledge diffusion seems to better grasp the contextual aspects of technology transfer in catching-up context, while also providing more informative input for policy-making.

Keywords: technology-transfer processes, diffusion of knowledge, university-industry-state relations, catching-up innovation system, biotechnology.

1. Introduction

Regardless of the fact that most innovation studies follow the evolutionary innovation systems perspective, most innovation policy practices have been following the linear model (Edquist 2014; Martin 2012). We concentrate on one element of the innovation processes – transfer of technologies from academia to industry – that is in the policy rhetoric often treated as the key indicator of innovation system performance. While conceptually, innovation systems should embody the complementarity between knowledge-generation and knowledge-exploitation subsystems (Cooke 2004), the existing discussions and policy practices of technology transfer tend to be locked in the one-sided linear view, where the demand-side issues and the industrial structure of national as well as global economy remain underemphasized (e.g. Polt et al. 2001a, 2001b; Uyarra 2010; Wright 2014; Audretsch, Lehmann, and Wright 2014; Bozeman, Rimes, and Youtie 2014).

In Europe, the narrative of European Paradox has been used to frame this policy logic and legitimize the focus on technology transfer and commercialization policies. At the same time, critical studies have shown throughout the last decade (e.g. Dosi, Llerena, and Labini 2006; Powell, Owen-Smith, and Colyvas 2007; Bonaccorsi 2007; Mowery 2011) that not all countries suffer from the paradox and need the same medicine. The reliance on ill-defined policy rationales explains also the contradiction between policy rhetoric and practice: in policy talk, research valorization is primarily equated with technology commercialization and spin-out formation, but its substantive status in academic research practice, at least in comparison to science excellence (publications, citations), is believed to be still secondary (Philpott et al. 2011; de Jong, Smit, and van Drooge 2016). Thus, while research in the technology transfer field has arguably reached to the phase of maturity (Wright 2014, 322), we believe that the lack of context-specific evolutionary approaches to the varieties of (sectoral) innovation systems may be one of the reasons behind the ongoing mismatch between research and practice.

Especially in the countries and regions in the catching-up phase, such as Central and Eastern Europe (CEE), the innovation systems are by definition immature, emergent and unevenly integrated with global production and innovation networks (e.g. Radosevic and Stancova 2015). Further, such countries tend to rely on the narrow perspective of national innovation system (see in general, Lundvall 2007; R. R. Nelson 2004) and emphasize policy emulation and copying of the 'right' institutional set-up as the main recipe (Karo and Kattel 2010). In CEE countries, the mechanical transfer of *Western policy models* together with the focus on commercialization and university-industry cooperation has been the most legitimate way of policy-making (Radosevic 2011, 36), even if this does not allow to tackle the main problems these countries face (Suurna and Kattel 2010).

In this study, we analyze the development trajectories of existing academic business ventures –cases of academic spin-off creation and technology and knowledge diffusion. Our cases come from one extreme CEE catching-up economy – Estonia – where the linear technology transfer models and commercialization rhetoric has been at the core of the innovation policy (see Izsak, Markianidou, and Radosevic 2014; Havas et al. 2015) and one sector – biotechnology – where one could expect from the global experiences that the linear model and rhetoric might be best fitting (see Pavitt 1984). This way we control for the technology-specific explanations and test the context-specific capabilities in theoretically best-fitting national context and technology sector (if the logic does not work in Estonian biotech, it is unlikely to work in other catching-up economies and sectors as well). We focus on the following research questions: a) *How has the Estonian biotechnology sector performed in commercialization of public research?* b) *What are the drivers and barriers affecting the feasibility of commercialization of public research as perceived by the main actors (entrepreneurs and entrepreneurial academics)?*

Through analysis of these questions, we show that as opposed to linear models to innovation and technology transfer, the evolutionary approaches seem to better grasp the contextual aspects influencing technology transfer in catching-up innovation systems. This study is structured as follows. In Section 2 we highlight some of the main failures of the linear perspective on technology transfer and provide an alternative systemic perspective that places a stronger focus on the diffusion processes and dependence of technology transfer on the wider context of innovation system. Section 3 provides detailed background information about the Estonian case. Section 4 describes the research methodology. The results of the analysis are presented in Section 5. The wider discussion, together with possible policy implications, is provided in the concluding section.

2. From a linear to a systemic understanding of technology transfer

The term *technology transfer* refers to 'organizational and institutional interactions involving some form of technology-related exchange' (Bozeman 2000, 629). Even though technology transfer, but also technology commercialization more specifically, is ideally seen as a dynamic two-way process between university and industry/market, affected by different factors and challenges throughout the whole process (Etzkowitz 2014, 14; Jolly 1997), the existing discussions seem to be structured though static categories and limited analytical perspectives. Especially the dynamism of the entrepreneurial processes as well as the potentially varied impacts of technology transfer tend to be underemphasized in the literature (Mustar et al. 2006). These somewhat simplified assumptions tend to determine also how the (economic) benefits of (publicly funded) basic research are measured and evaluated. In order to capture the evolutionary process of technology transfer, we stem from the following key building blocks.

First, the predominant technology-transfer models presume that the *object of transfer is predetermined* at the very beginning of the process. The (policy) focus tends to be on how to make the objects *robust* enough to get them 'out-the-door' (Doganova 2013). The systemic underpinnings – supply and demand context – for the technology transfer have received considerably less attention. A. J. Nelson (2012) has argued that quantitative indicators of patents, licenses and start-ups capture only some parts, the later stages, of the innovation model. Based on European (failed) attempts to emulate the US rhetoric and practice, a critical stream of literature emphasizes that the policies and policy instruments supporting the science and industry interface are strongly affected by the structural differences in innovation systems and by the broader orientation of the institutional framework of each economy (Mowery 2011; Powell, Owen-Smith, and Colyvas 2007; Bonaccorsi 2007). Bonaccorsi (2007) has shown here that the arguably weaker performance (in terms of patents, licenses, start-ups) of European research systems stems from the systemic elements of the innovation systems, such as lower specialization in the areas of 'general-purpose technologies' with a variety of diffusion pathways and applications.

From the evolutionary perspective, the policy 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 necessary for entering international networks 'where the new technologies are being hatched' (Mazzoleni and Nelson 2005, 9). The latter is particularly important for catching-up innovation systems where the reliance on foreign-made technologies and the respective capability building tends to be more important than the indigenous R&D efforts (Tiits, Kalvet, and Mürk 2015; in general, also Perez and Soete 1988).

Second, there is a *wide spectrum of patterns that remain under-emphasized* by the linear and formalistic approach of technology transfer, especially the feedback linkages within the development processes such as 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; A. J. Nelson 2012; Doganova 2013). This spectrum includes also technology transfer through idea generation in university-industry interaction, labour mobility, influx of students (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. These are all essential in the diffusion of basic research and its specification for the needs of the industry, but are not so easily distinguishable into distinct and formal phases/elements (Salter and Martin 2001; Cohen, R. R. Nelson, and Walsh 2002; Bekkers and Bodas Freitas 2008; Bozeman, Rimes, and Youtie 2014).

Third, the linear model puts most emphasis on the *commercialization of valuable discoveries as an objective in itself*. This is reflected in the high importance given to 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) (Philpott et al. 2011; Bozeman, Rimes, and Youtie 2014; de Jong, Smit, and van Drooge 2016). This has been reinforced by the decreases in direct (stable, institutional) public funding of basic research (e.g. Etzkowitz et al. 2000; Coccia and Rolfo 2008; D'Este and Perkmann 2011).

The narrow focus on the commercialization of R&D results fails to tackle more systemic problems of industrial transformations, especially in catching-up economies (Tiits, Kalvet, and Mürk 2015). Thus, from the more systemic-evolutionary perspective, Bozeman, Rimes, and Youtie (2014) call for paying complementary attention to the issue of *public-value criterion and impacts* (*was it beneficial*?) next to sole focus on economic benefits (*was the technology transferred?*) of technology transfer. Further, the prevalent narrow focus for the assessment of market impact/ economic development captures only microeconomic impacts (firm sales and profitability), but is limited regarding systemic achievements and sustainability issues (Ibid.).

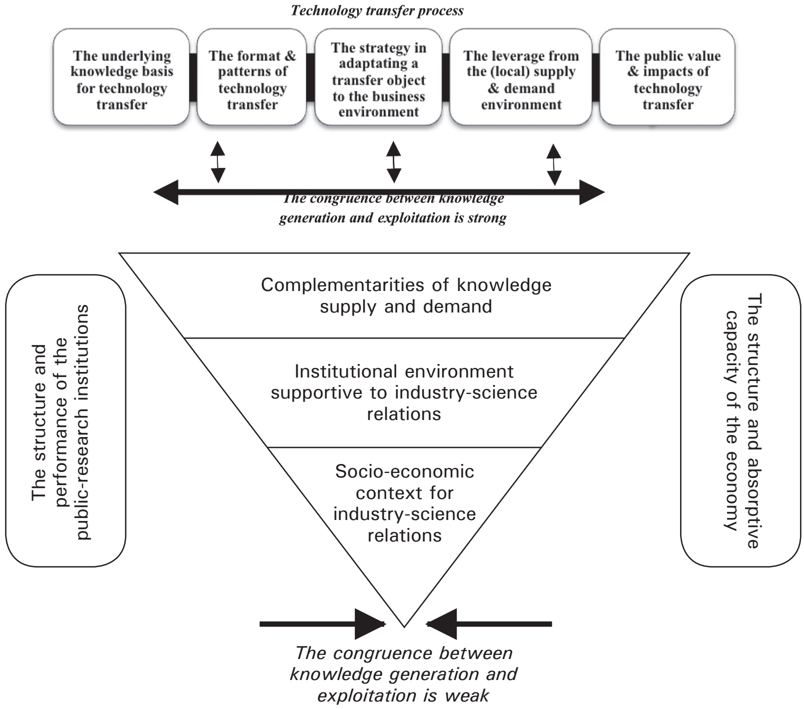
Fourth, once the linear approach shifts the analysis from scientific to entrepreneurial issues, technology transfer is assumed to be a *rather straightforward process* (see Mustar et al. 2006). Attention has been given to the early stages of venture development focusing on how ventures grow out of a scientific sphere. The crucial elements emphasized include the variety of distinct sets of competencies (e.g. the discovery and identification of commercial opportunity), the role of individual characteristics to take a championing role in the process, the capabilities for resource acquisition (e.g. Rasmussen, Mosey, and Wright 2014; Wright, Birley, and Mosey 2004; Druilhe and Garnsey 2004), but also the importance of social networks and network ties (see Johansson, Jacob, and Hellstrom 2005; Scholten et al. 2015). In contrast to this resource-based view, whereby competitive advantage is dependent on the strategies for exploiting existing firm-specific assets, the concept on dynamic capabilities exemplifies the company's (varied) ability to adapt to the changing environmental conditions (Teece, Pisano, and Shuen 1997). So, the key is not whether and how the academic ventures are embedded into knowledge networks, but the notion that these relationships are highly dynamic as well (Perez and Sanchez 2003). It has also been argued that there is a scope for further research regarding the post-formation product development and growth of spin-off companies with focus on the issues related to technology regimes, lifecycles and market factors (tendencies towards segmentation, the effectiveness of patents, the importance of complementary assets) (Djokovic and Souitaris 2008).

Finally, the dominant literature hardly discusses *how the ventures that grow out of the public R&D system are affected by the local supply and demand environments*. Yet, from the systemic perspective, technology transfer should *not be seen as an independent process*, but one that is directly linked with the wider complementarities between supply and demand environments and systemic knowledge transfer and absorptive capacities (Bozeman 2000; Polt et al. 2001b). Muscio and Vallanti (2014) demonstrate that one of the key barriers to establishing university-industry collaborations is finding innovative companies to collaborate with. The issue of complementarities is highly relevant in the case of biotechnology sector where research and early exploitation tend to be highly regionalized while the development, distribution and marketing are highly globalized industrial spheres (Kaiser and Prange 2003).

So, while the technology-transfer policies, especially in Europe, have mostly focused on developing different intermediation institutions (public-promotion programmes, intermediary infrastructures, legislation and institutional settings), the issues of how to implement these measures and how to evaluate their impact have received limited attention (Martin and Tang 2007; Polt et al. 2001a, 2001b). Also, the demand side issues, such as identifying '*the company-specific conditions that must be present to allow spending on R&D to positively affect growth*', have been largely neglected (Mazzucato 2013, 44). Further, one has to acknowledge that the framework conditions are not only specific to certain national and international industry networks, but also to different economic sectors and fields of technology – university-industry linkages will vary along with market conditions, demand and technology characteristics (Polt et al. 2001a). In the catching-up 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 (Suurna 2011, 102).

In sum, from the systemic perspective technology transfer should be treated as a multi-step process combining the knowledge generation sub-system and knowledge exploitation and diffusion sub-system that is a dynamic process strongly embedded in and affected by the structural underpinnings of innovation systems. One of the typical characteristics of catching-up innovation systems is the limited congruency between knowledge generation and exploitation sub-systems. The bigger the differences in the specializations of universities and economic sectors, the more (policy) efforts, time and investments are needed to induce long-term congruence between the sectors and increase the socio-economic impact of technology transfer (see Figure 1).

Figure 1. A systemic perspective on the technology-transfer process and complementarities



Source: Authors, in relying on Polt et al. 2001a, 2001b; Bozeman, Rimes, and Youtie 2014.

3. Stylized facts about the Estonian biotechnology sector

Since explicit innovation policy emerged in Estonia in late 1990s and early 2000s, one of the main policy priorities has been to develop measures for technology transfer and commercialization, e.g. supporting setting-up technology transfer offices in universities, revising patent and licensing laws, adding patents and licenses as criteria in R&D evaluations, supporting cluster and network building between academia and industry, funding co-initiated and co-implemented R&D projects (Karo 2010; Suurna and Kattel 2010). Biotechnology has been explicitly prioritized in all national innovation strategies since 2004 and today it is one of the smart specialization priority areas.

The overall scientific capacities of Estonia have strongly concentrated in the fields related to biotechnology, mainly molecular biology and genetics and biochemistry, which constitute the leading academic fields in Estonia (in terms of total citations, citations per paper relative to the world average; see Allik 2015, 9).[4] Based on the advancements in biotechnology-related science, Estonia has been also labelled 'a poster child for successful transition to Western-style science' (Nature 2009a, 2009b).

At the same time, the total number of international patent applications (EPO, WIPO, USPTO and other) has shown a decreasing trend between 2000-2016. Estonian researchers and universities have been the key applicants (37% of applications), followed closely by institutions or companies registered abroad (35%). The role of local enterprises has been more modest (28%) and the most active actors have come from traditional and relatively mature disciplines. The total number of US utility patents granted to the Estonian biotech scientists remains marginal (37 patents); this is 10% of all US patents granted to entities involving Estonian inventors (see also Figure 1 in Appendix; Karo et al. 2014).[5]

Estonian R&D and innovation policy has been rather successful in incentivizing scholars to produce internationally competitive scientific papers, but the focus on socio-economic relevance has suffered from this policy focus (Lember et al. 2015). There are no effective mechanisms in research evaluation and funding policy that take such research into account. According to Ukrainski, Kanep, and Masso (2013, 16), Estonian bio- and environmental sciences have largely relied on public sector funding oriented towards research excellence. As the result, the size of R&D contracts has remained insignificant and concentrated in a few institutes and research groups of the field (Kirs, Karo, and Lumi 2017; see also Figure 2 in Appendix). Also in general, funding of R&D expenditures in the Estonian higher education institutions by the local businesses (5% in 2015) is not only limited in comparison to public funding but also to Foreign Funds (15%) (Statistics Estonia 2016).

At the (local) industrial level, more than half of the companies (75 in 2014) that identify their main activity as biotechnology R&D were established between 2007-2014 when significant amount of EU funding was targeted through the Knowledge-based Estonia strategy to R&D and innovation prioritizing biotechnology and emphasizing technology transfer and commercialization. Based on information about ownership structures and board

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4 The total number of research groups active in the field of biotechnology is approximately 43, converging mainly into *University of Tartu* (UT) (28; specializing in molecular and cell biology, gene technology and biochemistry) and *Tallinn University of Technology* (TUT) (12; specializing in neurobiology, cancer biology, gene technology of plants, system biology and fermentation technology research) (Karo et al. 2014). As seen in the study by Allik (2015), TUT has failed to reach to top 1% in any fields of science (22 in consideration).

5 The total number of patent applications filed by the institutes under consideration was 173 in total in October 2016.

membership, majority of these enterprises can be affiliated with the main R&D institutions. Most of these newly established biotechnology companies have grown out, as second round academic spin-offs, from already existing enterprise groupings (Suurna 2011; Kirs 2016). In line with the criticism raised by Pisano (2006; also Hopkins et al. 2007), this expansion of the industry has created a large number of (unstable) micro enterprises. This has gone hand in hand with the evolution of business models and growing emphasis on risk-management strategies rather than R&D-intensive synergies and specializations (Kirs 2016). One has to note that sales revenues in the field for 2015 were 35.8 mln EUR, forming only around 0.07% from the economic activities in Estonia (Statistics Estonia 2017).

Thus, one can conjecture that there is a structural chasm between the scientific and entrepreneurial orientation of the R&D institutions and the demand context and capabilities in the Estonian biotechnology innovation system, which the prevalent policy rhetoric overlooks.

4. Research methods and the sample of the cases

In contrast to the prevalent research strategies, this study approaches the transformation of academic research into economic realm by focusing on the entrepreneurial processes underlying technology transfer. We concentrate on the evolution of business ventures that have grown out of the Estonian R&D system and have succeeded to generate socio-economic impact. As the information on the solutions, technologies, methods grown out of the public R&D system is neither systematized nor comprehensive, we relied on explorative strategy and snow-balling method to compile a purposeful qualitative sample of *successful cases* of technology transfer in the Estonian biotechnology sector (see Table 1). By *successful* cases we do not only mean enterprises with a history of significant sales and revenues, but also substantive development of alternative or complementary technologies (Audretsch and Link 2012).

The sample covers two different modes of knowledge and technology commercialization: (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 sample of cases is representative as it covers activities of the most important research groups and enterprises of the sector.

For our analysis, we relied on the different data sets. First, extensive desk research was conducted to detect and analyze the evolution of the successful cases of technology transfer. Different public sources of information were analyzed in depth, including the media coverage and reports of financial activities in the Estonian Commercial Register (*Äriregister*). Second, we conducted interviews to gather further details and participant perceptions on the main factors influencing the patterns of technology transfer and diffusion in the Estonian biotechnology sector. We interviewed 12 representatives – general and R&D managers – from all major enterprise groups and government financed biotechnology competence centres, which function as private R&D consortia. In addition, given the great fusion between the academic and business spheres in the Estonian biotechnology sector, we carried out 8 interviews with the leaders of different biotechnology research groups. As the perceptions on the technology transfer processes are not only covering the side of academics as it has been an overwhelming tendency so far (e.g. Ankrah et al. 2013) but also the side of entrepreneurs, a more systemic and comprehensive picture about the problems bounded to university-industry-state interaction is aimed to be provided.

Table 1. Sample of the cases

The case	Type of venture	Initiative for TT	Underlying knowledge basis for TT	The format of TT	The key strategy in adaptation to the business environment	The impact of the (local) demand environment on TT	The role of (local) public policy measures on TT	Key socio-economic effects of TT
Case no 1	Established in 1989; became a spin-off of TUT in the mid-2000s	A group of academics (affiliation to the current Department of Chemistry, TUT)	International R&D project + local analytical capabilities	Informal and uncodified (staff)	Service provision relying on speed- and cost-advantages	No direct impact; dependent on international value-chains (in relation of which high volatility due to service provision mentioned). Acquired by MNC in 2008.	No direct influence from Enterprise Estonia (EAS) policy instruments. Related to Competence Centre (CC) for Cancer Research.	Establishment of production facilities; important employer in the field of organic chemistry; a practical site
Case no 2	Spin-off of UT Established in 2006	Academics + entrepreneurs + US venture capitalists (affiliation to Institute of Chemistry, UT)	Local analytical capabilities in	Informal and uncodified (staff)	Service provision relying on speed- and cost-advantages; One of the founder's significant background in TT issues	No direct impact; dependent on international value-chains mainly (in relation of which high volatility due to service provision mentioned)	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. Related to CC on Health Technologies.	Important employer in the field of organic chemistry; with high export revenues; a practical site
Case no 3	Spin-off of UT and Estonian Biocentre Established in 1998	An academic entrepreneur + an entrepreneur + US venture capitalists (affiliation to Estonian Genome Centre, also Institute of Molecular and Cell Biology – UT, Estonian Biocentre)	*Postdoc* period of the leader in the US + international R&D project in 1998/1999	Technology + informal and uncodified (knowledge in PCR, in particular)	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). Related to CC on Health Technologies.	Development of DNA tests and services and the respective technology; one of the biggest employers in the field of biotech; a practical site
Case no 4*	Spin-off of UT Established in 1999	An academic entrepreneur + representatives of clinics – co-working area (affiliation to Institute of Molecular and Cell Biology, UT)	*Postdoc* period in the US	Technology + informal and uncodified (knowledge in PCR, in particular)	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 programmes supportive to the transfer decision and period); influence on R&D projects restricted (the company's resources have been sufficient). Related to CC for Cancer Research.	Development and provision of new types of diagnostic services to the Estonian medical sector; one of the biggest employers in the field of biotech; a practical site

Case no 5**	Spin-off of UT Established in 1999	An academic entrepreneur (Ibid.)	*Postdoc* period in the US	Technology + informal and uncodified (staff)	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. Related to CC on Health Technologies.	Platform technologies important for development of new drugs, vaccines, etc.; important employer in the field of biotech; a practical site
Case no 6***	The case of surrogate-entrepreneurship related to UT Established in 1999	Contract research to a Finnish company (Ibid.)	Joint publication	Informal (specific capabilities)	Founding a subsidiary in Estonia (incl. investments in infra) to feed into cooperation with (UT) scientists	If at all, the quality/cost ratio	Funding from TEKES (Finnish agency).	Experience & well-paid work; development of gene vaccines; facilitating biotech entrepreneurship in Estonia
Case no 7	Some enterprises of the Group have been formed legally as spin-offs of TUT Established in 2003	Contract research to the US partner; few academic entrepreneurs + venture capitalists (short term affiliation to Department of Gene Technology; partly also Centre for Biology of Integrated Systems, TUT)	Working experience from the US In principle, the company could have been established anywhere in terms of location	Informal and uncodified (staff)	Business model relying on allocation of different R&D activities / specializations to a number of different subsidiaries in the Group	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. Related to 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
Case no 8	Students' spin-off of UT Established in 2008	Classmates + an academic entrepreneur as a co-owner/ consultant (affiliation to Institute of Technology & Institute of Chemistry, UT)	Local + increasingly international capabilities and capacities	Informal and uncodified (staff) + contracts to international R&D institutions	Gathering experience but also additional funding via secondary activities Established a subsidiary in Germany	No; increasingly affected by the German development context; also international R&D projects.	Substantive influence on the side of EAS since foundation of the company. Significant financial support by the Development Bank of Saxony, AufbauBank SAB.	Development medical devices
Case no 9	The case of surrogate-entrepreneurship related to TUT	Academic entrepreneurs + underground initiative by students (the related research activities go back to early 1990s) (affiliation to Department of Chemistry & Department of Food Processing, TUT)	Highest impact from the international R&D projects	Informal and uncodified (staff)	International orientation, financial independence and making money from the very beginning	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. Related strongly to CC of Food and Fermentation Technologies	Upgrading local mature-food industry; graduate school; contribution to creation of new good-quality jobs (over 60)
Case no 10	The case of surrogate-entrepreneurship related to UT	Classical case of TT together with patenting and license agreements (the related research activities go back to 1990s; the first patent granted in 2005) (affiliation to Institute of Microbiology & Institute of Biomedicine and Translational Medicine in large, UT)	International R&D project	Formal and codified (patent)	Active engagement of UT department for TT	Limited: exclusive license in Estonia held by one company; the direction on food supplements relying on international R&D. The regulative environment in the EU not supportive (claims on probiotics not approved by European Food Safety Authority)	EAS support has served as an important basis for building up the specific manufacturing capability and realizing the pilot project. Related strongly to the Bio-CC of Healthy Dairy Products.	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. TT – technology transfer; TUT – Tallinn University of Technology; UT – University of Tartu; CC – Competence Centre; EAS – Enterprise Estonia.
Source: Authors.

5. Perceptions on the technology transfer patterns in the Estonian biotechnology sector

5.1. The underlying knowledge basis for technology transfer

While the Estonian R&D and innovation policies emphasize the linear technology-transfer model, we managed to map only *a few successful spin-off companies and ready-made 'out-the-door' solutions* that could validate the functioning of the model. It has been rather exceptional for the codified knowledge grown out of universities to be passed on to companies in a neat format of technological solutions and IP. It has taken place only in some particular fields of molecular-diagnostics technologies and/or methods (cases 3, 4/5) and of food technologies (case 10). Codified knowledge has rather played a supportive role in the majority of cases and technology-transfer processes largely depend on the single entrepreneurial academics who themselves discover the market potential of their research. Thus, even the successful cases of knowledge transfer to spin-off companies should be seen primarily *as personal 'pet projects' of key people* behind the companies and outcomes of their personal aspirations, goals and interests. Furthermore, creation of these spin-off companies can be also done for the purpose of 'gaming' the system: creation of formal companies allows researcher to apply for both research and business support funding.

As one could expect from the systemic-evolutionary perspective, the technology transfer cases with significant economic impact have mostly emerged from research groups with high-level *international research excellence*. Very good levels of basic science, and public funding of basic research, were emphasized by most respondents as crucial prerequisites for knowledge transfer. Two of the successful cases (9 and 10) emerged from rather long periods of (fundamental) research going back to early 1990s. Conversely, the lack of basic capabilities and technologies in local universities explain why some businesses opted to cooperate with foreign partners (e.g. case 8).

International networking has been another important factor for knowledge development and transfer. Taking part in scientific conferences and international R&D cooperation projects (European Union's FP7, Horizon 2020) has not only served as a breeding ground for developing networks and contacts (cases 1, 4 and 10), but has provided significant public funding necessary for basic R&D and business activities (e.g. FP7 as a basis for the diversification of portfolio in the case 3). The foreign work and research experience (post-doc periods etc.), acquired knowledge and networks of key people have opened up certain 'windows of opportunities' to be realized in Estonia (cases 3, 4, 5 represent the transfer of PCR-related knowledge and skills; case 7, the actual entrepreneurial experience from the US). Overall, Estonian participation in joint research projects as well as international contract research has been based on speed- and cost-advantages supported by sufficient, not necessarily world-leading, professional competence. Essentially, these strategies have helped the spin-off companies to survive outside the public R&D system and develop their technology niches.

5.2. The main patterns of technology transfer

For characterizing the patterns of technology transfer, almost all respondents emphasized competent people (academic entrepreneurs who are shareholders and/or R&D consultants in the spin-off companies, qualified personnel and graduates) and *tacit* knowledge over codified knowledge and contractual relationships. The departure of scientists from universities to the industry has been rather exceptional and universities continue to play a significant role in providing a *shelter* for entrepreneurial researchers until a commercial niche has been found, or failure or exit from the system has taken place.

Thus, the ties between the academic and business networks are highly *personal*, *informal* and *long-term* (especially in case 1, 2, 7), which is a further deviation from the linear and biotech-based models in more developed innovation systems. As the domestic market is dominated by micro enterprises (established by academics) in the phase of infancy, there is no clear domestic demand for codified IP. At the same time, several interviewees claimed entering and competing in the foreign markets is considered to be too complex and difficult, at least based on existing R&D, strategic management and marketing capabilities. As a result, and as pointed out by several interviewees, a large share of biotechnology developments of the R&D system (also technology-based products) remain stuck in the development phase. The main reason is the differences in core routines of academia (to publish basic research) *vs.* industry (to develop credible products through experimental development with limited resources for applied research). By now, there are even application areas where industrial demand has become so specific in global niche value chains (e.g. oil-shale energy/chemistry) that it cannot be met by the domestic universities, which have not been able to acquire or maintain expected capacities.

On managerial level, the identified successful cases of technology transfer are characterized by *early decoupling* from the public R&D system. Typically, while the visionary scientist remain involved in the further in-house development (of new-generation technologies/techniques), the whole 'project' is coordinated and led by professional manager from the business sector ('a champion'). For example, in the case 4, after the early transfer of the technology to diagnose 6-7 pathogens, the in-house R&D team of the company developed the technology further (basically doubling the technology basis) while the management team searched for a functional business model (eventually service provision through logistics, supply, quality management services). This shift in the business model gradually reduced the links of a company with (domestic) research groups in universities (a common characteristic in emerging industries, Bodas Freitas, Marques, and e Silva 2013).

The dominance of the *contract research based business models* rather than production based on transferred codified technologies signifies the strong influence of the *demand conditions* on commercialization activities. The presence and influence of the first *core customer* largely determines the nature and impact of the transferred knowledge (especially crucial for the cases 1 and 2). These contracts are crucial for discovering possible R&D niches, for investing in business processes in general, and for accessing (global) value chains. It has become increasingly common within all major enterprise groupings (cases 2, 3, 5) to build business models through the separation of service delivery and R&D activities (including IP), whereas the former is considered more essential for survival. There are also companies (case 5) that have managed to establish themselves as specialized service providers in value chains and in these cases, the codification and protection of knowledge is considered neither cost-efficient nor necessary. The specialization of the companies into *specialized services* as opposed to developing of original products has further reduced the importance of codified knowledge.

5.3. The leverage from the (local) demand environment

Overall, the demand for biotechnology transfer from university to industry has been weak and indirect at best. A rather exceptional case is *the development of food technologies* (e.g. nutrition testing/development, fermentation) by the Competence Centre (CC) of Food and Fermentation Technologies and Bio-CC of Healthy Dairy Products (cases 9, 10). Paradoxically, this is one of the most mature and stable biotechnology related industries, where the relatively strict EU regulations regarding the safety and other aspects have been a crucial demand-creating driver. Codified knowledge has played a greater role here than in other sectors because the maturity of the industry provides more stable basis for defining specific applications where transferred knowledge and technologies could be applied and for formalizing these transfers through patents and licenses. These successful cases have emerged from joint R&D projects between CCs and its international partners and local food industry.

The other areas of biotechnology applications have not enjoyed such leverage from the local demand, which is also, why these sectors are still in the phase of development and building up local demand environment. In *pharmaceuticals* related activities, the business models are strongly oriented towards the *exit strategy*, whereas the specializations are aligned with the global focuses and investor interests (e.g. research on the cancer treatment). Overall, due to the complex regulatory environments, concentration of business activity in certain regions/markets may have both pros and cons. One of the interviewees admitted 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'. At the same time, the Estonian public sector context may offer globally unique possibilities, e.g. as claimed by one respondent:

> *One has to admit that the bureaucracy involved is not as extensive as in other (larger) European countries... 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.*

Although the local and international demand has created only a limited pull-effect for linear technology transfer, the overall demand conditions have clearly influenced the adaptation processes of the studied spin-offs. As noted earlier, contract research has been the key driver for technology transfer as well as key source of survival on the market. In addition, the service-dominant logic prevalent in most of the spin-offs has largely followed the existing local demand patterns. Here, the most important national demand-side actor is the governmental *Health Insurance Fund of Estonia* (the main health insurance provider) whose decisions to include certain procedures, methods, etc. on the list of reimbursed services has enabled several new technologies to emerge and diffuse (i.e. case 4 on molecular diagnostic services) and several start-up companies to find first customers in the early stage of development. As the lobby of medical associations and organized physicians influences these choices of the Fund, their early inclusion to technology transfer attempts, awareness of technological advancements as well as demonstration of cost-efficiency to hospitals and clinics are important aspects of demand management.

Even though public hospitals could be 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, cooperation with technology developers often relies on the enthusiasm of single individuals, as R&D is not prioritized in the current public-funding mechanisms and organizational strategies. On the other hand, enterprises find the clinical materials of the local hospitals not representative enough for global value chains oriented technology development.

5.4. The leverage from public policies

There are only a few companies that have managed to cover the development costs with own resources (including sales and other secondary activities; see Kirs 2016). According to the interviewees, given the current capabilities of the Estonian biotech innovation system, it is rather difficult to attract private investors to support and finance technology transfers and commercialization. For example, in one relative success case (10), the actual patent was granted in 2005 and by now, the owners of the patent have negotiated with more than 200 corporations, but only two agreements are active.

Thus, most successful knowledge transfer cases have been at least partly funded by the public sector (Enterprise Estonia, EAS; foreign national development banks and agencies), e.g.

> *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, the contract research essentially enables the development of these capacities that are to be commercialized later.*

However, the Estonian R&D and innovation support system, which has been for long time based on grant funding as opposed to loan guarantees, direct investments and tax-exemptions, is neither found to be patient nor appropriate enough to support more complex capacity-development efforts of the private sector. As argued by one respondent:

> *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.*

In order to reap the benefits from more patient (public) funding, some promising spin-off companies have moved into the hands of foreign capital already in the stage of more intensive applied research and development activities and before socio-economic returns were realized (case 8).

On the other hand, in some cases also a vicious circle of *subsidy-dependence* can be detected (see Kirs, 2016): the ability to successfully obtain state grants for further basic research often de-incentivizes spin-off companies from making more risky but necessary steps in product development and strategic management (to decouple from university R&D routines by, e.g. hiring professional managers, sales people etc.). 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 …. At the same time, there was a strong need for the money to be 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…*

It is crucial to note that the identified successful cases of biotechnology transfer 'go back' to the late 1990s and early 2000s when the innovation policy mix was still in its infancy. Thus, these cases *succeeded* due to several important factors working in combination, e.g.: *real demand and feedback* for the R&D (e.g. the inclusion of medical doctors as project consultants); the *personal choices and incentives* of the founding academics; *institutionalization of demand* in the Estonian health-care system by the Health Insurance Fund; *specific financial instruments* (Innovation Fund, the predecessor of the EAS) and national support programmes (SPINNO).

In the current policy mix, public funding (since 2004) of *competence centres* (CCs) that function as private R&D consortia co-owned by public universities and firms, has had a relatively unique impact. This is the only policy measure, which has tried to influence R&D activities and technology transfer processes not only through financial incentives, but by establishing and developing new organizational routines, networks and capabilities. CCs are financed by state while universities as first partners contributed their tacit and codified knowledge and companies participate mostly through in-kind contribution (secondment of staff). It emerged from our interviews that the more successful CCs (cases 9, 10) have evolved over time from more scientist-driven entities into *innovation and market-oriented* organizations where, if needed for technology transfer, the role of academics (and universities as shareholders) has been reduced and more development- and marketing-oriented staff has taken the central roles. Due to this design of the CC measure, significant part of academia-business cooperation takes place not directly between universities and businesses, but in these self-standing and formally private law entities that bring together tacit and codified knowledge and interested businesses in particular field. However, as these firms are the co-owners of these entities, the potential for wider technology transfer and socio-economic impact has been limited as there are competitive pressures and interests to keep these entities closed to other actors.

6. Concluding discussion and policy implications

The aim of our study was to provide better evidence of the evolutionary trajectories of the technology transfer processes in the CEE catching-up context. Estonian biotechnology sector was selected as the focus because of the centrality of technology transfer in Estonian innovation policy-making, while biotechnology represents the leading research field in Estonia and a classic case for linear technology transfer model. As seen from the Estonian case, the expectations of the linear technology-transfer model and related policy rhetoric are not achieved even in the field of biotechnology. We can say that focusing on narrow formal approach to technology transfer – treated as an ultimate end in itself – and re-enforcing this through policy and academic rhetoric does not fully support substantive technology and knowledge transfer and capabilities development. In fact, as there is considerable mismatch between the capabilities of public R&D institutions and (the local) industrial and public sector needs, the gap of complementarities in knowledge generation and exploitation sub-systems has become even wider and more structural.

Contrary to the expectations of the linear model, the prevailing pattern of technology transfer in Estonian biotechnology sector seems to be strongly tacit and informal. While a large share of the biotechnology enterprises has grown out of the public R&D system, the transferred codified knowledge plays, at most, supportive role in the business models of these enterprises. Several cases that would fit neatly into the format of a classic linear model were initiated when technology transfer policies were largely non-existing. Thus, they mostly benefitted and emerged from excellent scientific capabilities and personal incentives of key academics and their networks.

In addition, we can witness decreasing connections between business ventures and their original founding research groups. The linear rhetoric of technology transfer leaves the routines of R&D institutions and industry untouched and universities keep following strategies maximizing basic research (as these routines pre-date technology transfer policies) and are unwilling to shift towards serving corporate and public demand with different risks (shorter time frames, unpredictable funding). Thus, the universities are not motivated to develop experimental and applied R&D capabilities and the willingness by the private sector to finance the aforementioned initiatives directly or indirectly is more than limited as well. As it was shown through the specific technology transfer cases, the success stories of technology transfer have required both academic and business-related leverage from international financial and knowledge networks, which required high research and managerial capabilities rather than technology transfer capabilities per se.

Essentially, the paradox presented here is a classic outcome of the 'copying paradox': the focus on and belief in single policy measures takes the focus away from broader contextual issues. The policy focus on the formal technology transfer of codified bodies of knowledge has established rhetoric and expectations that are difficult to fulfil within the existing academic and business context. In essence, it does not matter 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 try to initiate changes. The key challenge is still to find the synergies between these two and develop long-term complementary specializations, which is a much broader task of industrial and innovation policies.

The artificial support to magnify the formalized university-business interactions has not only considerable limits in bridging the gap of capabilities in the two sectors, but it may result in shared disappointment in the overall idea of knowledge transfer and its feasibility. Some of the more promising cases of technology transfer have been transferred abroad prior to their expected socio-economic impact was realized. The competence centres policy support measure has been somewhat exceptional here as it has been the only long-term effort to search for and sustain new organizational routines and capabilities for technology transfer. Still, given the closed business model of these entities, the spillovers and broader impact has been limited. Given the influence of the EU and its funding instruments, an issue across CEE, technology transfer seems to be influenced by the vicious cycle of subsidy-dependence, while the actual socio-economic impact has remained limited.

In sum, the socio-economic impact of technology transfer depends on how policy-makers are able to take into account the sector specific aspects of technology transfer, even if transfer itself remains informal and tacit by nature. As for further research and for developing sector-specific policies, issues related to technology lifecycles 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) need to be taken into account as well. Analysis of the varieties in diffusion policies could be highly relevant for advancing the current debates on technology transfer and technology-specifity. So far, the fundamental problems of technology transfer tend to be treated as common for different technology fields (Cohen, R. R. Nelson, and Walsh 2002; Gilsing et al. 2011).

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APPENDIX

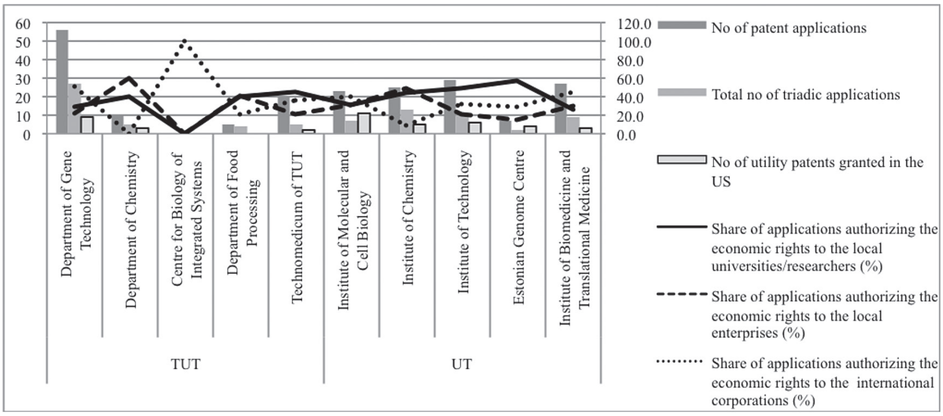

Figure 1. Patent applications filed by and patents granted to the R&D institutes included in the study

Note: Due to inter-organizational cooperation, some patent applications (30) and patents (6) are counted multiple times. In the case of Department of Gene Technology (TUT) majority of patent applications (nearly 20) are concentrated into the hands of one person; and his activity is primarily associated with one international corporation (Cemines Inc).

Source: The information was derived from the Estonian R&D database ETIS (October 2016); the information about utility patent grants was derived from USPTO database (October 2016).

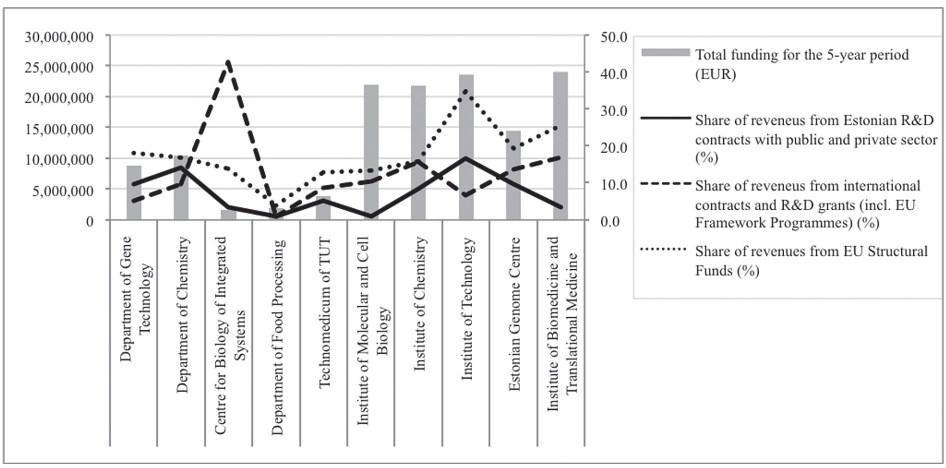

Figure 2. The structure of revenues at the level of main institutes relevant to biotechnology in Estonia over the 5-year period

Note: Due to data accessibility, the period under consideration covers the years of 2008-2012 in TUT case and 2009-2013 in UT case.

Source: Compiled by authors based on the data submitted by universities.

Working Papers in Technology Governance and Economic Dynamics

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