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Commercializing university research in transition economies: Technology transfer offices or direct industrial funding?

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ABSTRACT

There is a paucity of knowledge on research commercialization by university scientists worldwide. The objective of this paper is to identify the role that Technology Transfer Offices (TTOs) and direct Industrial Funding play in university research commercialization in transition economies of Azerbaijan, Belarus and Kazakhstan during 2015–2017. We do this by developing a novel database and a multi-level model which explains how individual attributes, organizational and ecosystem characteristics explain the extent of knowledge commercialization.

We apply the generalized Heckman approach to account for two selection biases, reducing the sample from 2602 to 272 scientists, and further use a mixed-method approach to analyse 27 face-to-face interviews with researchers and TTO managers. The results demonstrate that research commercialization is not associated with the existence and awareness of TTO or the establishment of commercialization contracts via TTO, but the direct industrial funding of university research. Taken together the findings have clear implications for scholars, scientific entrepreneurs, TTOs and investors who aim to exploit university knowledge in transition economies.

1. Introduction

The role of contemporary universities has become multifaceted (Etzkowitz et al., 2000; Bishop et al., 2011; Perkmann et al., 2011a, 2013; Hvide and Jones, 2016) and encompasses teaching, research and entrepreneurship function (Audretsch, 2014). Universities implement far-reaching changes to become more entrepreneurial (Mets, 2009; Siegel and Wright, 2015; Cunningham and Link, 2015; Díez-Vial and Montoro-Sánchez, 2016) and technology transfer processes are being set up to promote research commercialisation (Lockett et al., 2003; Lockett and Wright, 2005; Phan and Siegel, 2006). Research commercialization requires building a strong external partnership with ecosystem stakeholders (Bogler, 1994; Bozeman and Gaughan, 2007; Bekkers and Bodas Freitas, 2008; Miller et al., 2014; Acs et al., 2017) such as entrepreneurs, universities, local and national government, private industry.

The financial returns from and mechanisms of university knowledge transfers have remained under researched and have triggered an interest across entrepreneurship scholars and policy makers in developed countries (Chapple et al., 2005; Wright et al., 2006; Kenney and Patton, 2009; Kalar and Antoncic, 2015; Abreu et al., 2016) and developing countries (Sedaitis, 2000; Varblane et al., 2007a, 2007b; Bajmócy et al., 2010; Marozau and Guerrero, 2016; Guerrero and Urbano, 2017).

Responding to public research commercialization opportunities, universities have explored a number of models of university knowledge transfer with entrepreneurship centres, university incubators, science parks and TTOs performing a role of a conduit (Link et al., 2007; Siegel et al., 2003, 2007; Wright et al., 2008; Kenney and Patton, 2009; Muscio, 2010; O'Kane et al., 2015; Kolympiris and Klein, 2017).

Although substantial research in the field of academic entrepreneurship has been conducted in developed economies (Siegel et al., 2003, 2004; Powers and Mcdougall, 2005; Phan and Siegel, 2006; Perkmann et al., 2011a,b; Ankrah and al-Tabbaa, 2016; Mosey et al., 2017), the field remains fragmented and incomplete in transition economies (Varblane et al., 2007a,b; Marozau and Guerrero, 2016). Empirical evidence of how knowledge spills at universities and reaches industry is very limited in these countries (Radosevic, 1998; Kwiek, 2012; Leydesdorff et al., 2015; Huyghe et al., 2016).

There is a lack of relevant data on the mechanisms of knowledge transfer from universities, regulation, incentives, culture and the external investment in research (Tchalakov et al., 2010). While the TTOs remains a new phenomenon, direct industrial funding has demonstrated its strength as a conduit of university knowledge transfer (Boardman and Ponomariov, 2009; Czarnitzki et al., 2015, 2016). Direct industrial

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funding is defined as industry's direct financial support for the development of technology by a university scientist(s). To the best of our knowledge, no research to date has established and empirically tested the role that university TTO and direct industrial funding play in research commercialization by scientists in transition economies (Grimaldi et al., 2011; Bradley et al., 2013; Guerrero et al., 2016; Theodoraki and Messeghem, 2017). This study bridges the gap.

Adopting the TTO perspective of the knowledge spillover theory of entrepreneurship (KSTE) in organizations (Acs et al., 2013; Shu et al., 2014) and the stakeholder perspective to entrepreneurship ecosystem framework (Grimaldi et al., 2011; Miller et al., 2014), we respond to the call in academic entrepreneurship literature (Aldridge and Audretsch, 2011; Perkmann et al., 2011a,b, 2013; Siegel and Wright, 2015; Mosey et al., 2017) and entrepreneurship ecosystem literature (Acs et al., 2014, 2017) - to investigate research commercialization in transition economies, while accounting for a broad range of individual, organizational and ecosystem level characteristics (Link and Siegel, 2005; Boardman and Ponomariov, 2009; Kenney and Patton, 2009; Stam and Spigel, 2017). These characteristics include professional level attributes such as amount of local and international publications, position, workload, research sponsorship, TTO collaboration and awareness as well as organizational level characteristics (university ownership, availability of TTO, contract relationship with TTO) and ecosystem level characteristics related to scientist's research funding by government, private industry in a home country and abroad, affiliated university, foreign universities or institutions, non-for-profits, other public organizations).

We start with the premise that there is a substantial variation in traditional and alternative models of university technology transfer (Siegel et al., 2003, 2004; Kenney and Goe, 2004; Bradley et al., 2013), that governs scientist's decision-making on research commercialization (Kenney and Patton, 2009).

We use the unique primary data on 2602 scientists collected by online survey in Belarus, Kazakhstan and Azerbaijan between November 2015 and August 2017. Having applied for two potential selection bias corrections: one for commercialization income disclosure and another for commercialization activity, our final model consists of 272 scientists. Belarus, Kazakhstan and Azerbaijan are representative transition economies with substantial research commercialization activity, with residents and non-residents currently hold 2503 (Belarus), 3218 (Kazakhstan) and 345 (Azerbaijan) World Intellectual Property Organization (WIPO) active patents (WIPO, 2018).

We validate our empirical findings with a mixed-method analysis of 27 face-to-face interviews with researchers and TTO managers during April 2016 – September 2017. A mixed method approach was demanded, because we had a compelling reason to suspect that measuring and analysing the commercialization of university research by relying solely upon data collected by the TTOs (Aldridge and Audretsch, 2011) or universities (Caldera and Debande, 2010) may lead to a systematic underestimation of knowledge transfers.

Taken together our results suggest that TTO activity neither impede nor facilitate research commercialization by scientists, while direct industrial funding stands as an efficient conduit for research commercialization. Although most scientists expressed their support to the "Professor Privilege" –type system (Hvide and Jones, 2016), vesting ownership with the inventor (Kenney and Patton, 2009) may take years in the troubled transition context.

The next section introduces the theoretical framework and formulates the research hypotheses. Section 3 describes the data and methodology. Section 4 describes results. Section 5 discusses the paper's main findings and Section 6 concludes.

2. Background literature

2.1. Knowledge transfers from universities to industry

Over the years, several scholars have studied the process of transferring knowledge from universities (Gulbrandsen and Smeby, 2005; Grimaldi et al., 2011; Aldridge and Audretsch, 2011; Freitas et al., 2013; Díez-Vial and Montoro-Sánchez, 2016; Guerrero et al., 2016) which could be either intentional (knowledge transfer) or unintentional (knowledge spillover) (Audretsch et al., 2005; Audretsch and Keilbach, 2009). Prior research identified stakeholders that facilitate knowledge adoption and commercialization such as TTO, and the channels of commercialization, such as licencing technology (Bradley et al., 2013) and university spin-offs, that represent one of the most visible forms of knowledge transfer (Di Gregorio and Shane, 2003; Lockett et al., 2003). Even though the knowledge transfer is often formalized (Siegel et al., 2003, 2004), the role of scientists in the knowledge transfer is not obvious (van Looy et al., 2004; Grimaldi et al., 2011). The term scientist is used as a descriptor for a university researcher.

As in any entrepreneurial process, there are individual, organizational and contextual filters that limit the knowledge transfer and prevent a complete transformation of knowledge into economically viable products (Acs et al., 2013; Guerrero and Urbano, 2014; Shu et al., 2014). The economics of entrepreneurship allows us to understand the main environmental factors that influence the organizational filters (Guerrero and Urbano, 2012, 2014; Miller et al., 2014), while the KSTE explains the role of regional, organizational and individual characteristics in the knowledge transfer (Kenney and Goe, 2004; Guerrero and Urbano, 2014; Urbano and Guerrero, 2013; Shu et al., 2014). The "Bayh-Dole" Act and "Professor Privilege" system are often used as an example to explain how individual, organizational and contextual filters could be effectively leveraged so that knowledge transfer takes place between scientists and industry (Perkmann and Walsh, 2010; Grimaldi et al., 2011; Aldridge and Audretsch, 2011; Hvide and Jones, 2016).

Unlike European economies (Wright et al., 2007, 2008), transition and developing economies have never experienced neither "Bayh-Dole"-type regulation in the US (So et al., 2008; Korosteleva and Belitski, 2017) nor "Professor Privilege –type system in Germany (Czarnitzki et al., 2015) and Norway (Hvide and Jones, 2016). Studies seeking to explain knowledge transfer from a university using the KSTE at the organizational and individual levels (Audretsch et al., 2005; Acs et al., 2013; Guerrero and Urbano, 2014) have identified a number of internal (organisational) and external (environmental) factors that either facilitate or impede the process of knowledge transfer. One important factor is the establishment of a university TTO (Siegel and Wessner, 2012; Siegel and Wright, 2015) and engagement with private industry (Clarysse and Moray, 2004; Boardman and Ponomariov, 2009; Clarysse et al., 2011; Díez-Vial and Montoro-Sánchez, 2016). The differences between the traditional KSTE and a TTO perspective of the KSTE are described in Table 1 using Shu et al.'s (2014) classification criteria.

2.2. Determinants of knowledge commercialization: a multilevel model

The process of research commercialization is a multi-level and involves interactions between an individual researcher, a university and the external environment (Powers and McDougall, 2005; Guerrero and Urbano, 2014; Theodoraki and Messeghem, 2017). Freitas et al. (2013) distinguish two modes of interaction: the institutional mode, which involves interactions between the university and ecosystem stakeholders (industry, government, non-for-profit, angel investors); and the personal contractual mode, which is a formal and informal collaboration between ecosystem stakeholders and scientists, carried out with or without the direct involvement of a university. Building on Freitas et al. (2013), Grimaldi et al. (2011), Perkmann et al. (2011a, 2013) and

Table 1
A TTO perspective of the knowledge spillover theory of entrepreneurship.
Source: Authors with criteria adopted from Shu et al (2014)

	Traditional KSTE framework	KSTE in TTOs
Empirical existence	National and regional levels (Acs et al., 2013, 2014; Audretsch, 2014)	Organizational level (Shu et al., 2014) with an individual perspective of the KSTE (Guerrero and Urbano, 2014) and university perspective (Audretsch et al., 2005; Audretsch and Keilbach, 2009)
Theoretical bases	Endogenous growth theory (Arrow, 1962) KSTE in various contexts (e.g. university, region, city) (Audretsch et al., 2005; Shu et al., 2014)	Entrepreneurship ecosystem theory (Stam, 2015; Stam and Spigel, 2017), the evolution of technology transfer competencies at universities (Clarysse et al., 2011; Ankrah and Al-Tabbaa, 2016)
Contextual factors	Regional level and entrepreneurship environment (Kenney and Patton, 2005; Agarwal et al., 2010)	University entrepreneurial orientation (Aldridge and Audretsch, 2011; Grimaldi et al., 2011; Kalar and Antoncic, 2015)
Knowledge filters	Formal and informal institutions (risk aversion of stakeholders, legal restrictions, bureaucracy, labour market rigidities, taxes, and lack of cognition and trust) (Agarwal et al., 2010; Shu et al., 2014)	Knowledge management and commercialization (Audretsch, 2014).
Knowledge spillovers	Investment in knowledge, collaboration and labour mobility (Acs et al., 2013), creativity (Audretsch and Belitski, 2013)	Knowledge transfer and knowledge spillover from the university to ecosystem stakeholders (Grimaldi et al., 2011; Guerrero and Urbano, 2014)
Relationship between knowledge filters and spillovers	Indirect (Agarwal et al., 2010; Acs et al., 2013)	Indirect (Acs et al., 2013)
Consequences	Entrepreneurial performance is measured at regional or national levels (new business start-ups, survival, quality of entrepreneurship, high growth)	Commercialization income of a scientist and/or TTO

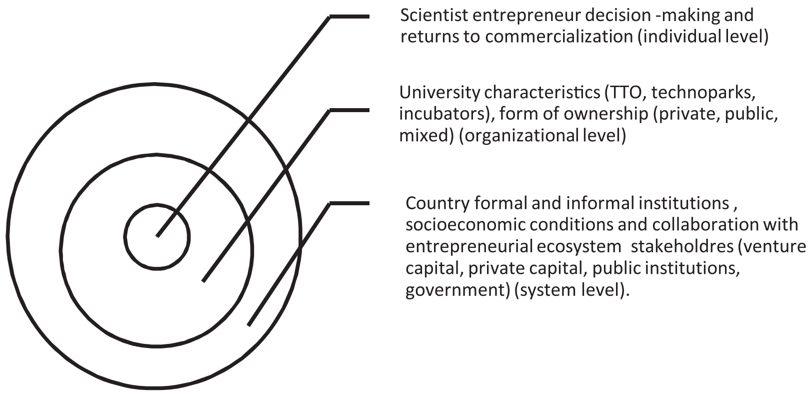

Fig. 1. Multi-level model of university research commercialization.

Guerrero and Urbano (2014), Fig. 1 illustrates a three-level model of university research commercialization, which connects scientist's behaviour, organizational structures and ecosystem environment factors (Aldridge and Audretsch, 2011).

The first (system/ecosystem) level of analysis focuses on the business and socioeconomic environment (Cooke et al., 1997; Stam, 2015; Audretsch and Belitski, 2017; MIT REAP, 2017). National innovation activity, intellectual property (IP) and other institutional reforms (So et al., 2008), the role that policy makers can have in the university's commercialization activities (Florida and Kenney, 1988) and the variety of entrepreneurship ecosystem stakeholders either support or impede research commercialization. According to existing literature on entrepreneurial ecosystems the presence of stakeholders facilitates entrepreneurial decision-making (Audretsch et al., 2005; Audretsch, 2014; Ankrah and Al-Tabbaa, 2016; Stam, 2015). When the entrepreneurial ecosystem context is conducive, scientists at universities will leverage available resources and information via engagement with ecosystem stakeholders to transfer and commercialize new knowledge (Perkmann and Walsh, 2010; Acs et al., 2017). This creates strong links between scientists and university TTOs, where the invention is initially disclosed as well as between university and industry, where the invention is adopted and commercialized. Once the invention has been disclosed, TTOs will decide whether or not to further commercialize it (acquire a patent, discuss commercials potential the prospective users, market technology, negotiate licencing agreements, licence technology) (Cooke et al., 1997; Siegel et al., 2004; Link and Siegel, 2005; Shu et al., 2014). For this reason, the theoretical framework used to study the interaction between a university and ecosystem stakeholders, builds on the TTO's perspective of the KSTE.

In contrast, an entrepreneurship ecosystem with weak institutional context works in the opposite fashion (Wright et al., 2006, 2008). Below are the few examples. First, instead of disclosing the information to TTOs, which will later market the technology to organizations and entrepreneurs, providing revenues to the university, scientists will choose directly interact with private companies bypassing the university administration and TTOs (Thursby and Thursby, 2004). To access the extent of the alternative modes of research commercialization it is necessary to study the individual level data, measuring the relationship between scientist's behaviour and individual commercialization income. Second, as the invention has never been disclosed, the TTO will not be able to market it to entrepreneurs and organizations, will not negotiate the licence and not sign the licencing agreement. For this reason, the theoretical framework used to study the interaction between a scientist and ecosystem stakeholders, builds on the stakeholders' perspective to entrepreneurship ecosystem framework (Grimaldi et al., 2011; Miller et al., 2014; Stam, 2015; MIT REAP, 2017; Acs et al., 2014, 2017; Audretsch and Belitski, 2017). The literature distinguishes between five potential groups of ecosystem stakeholders who may be involved in university research commercialization: entrepreneurs, risk capital providers, universities (TTOs), policy makers (government)and large corporations (private industry).

The second (organizational) level of analysis focuses on universities and their ownership, the administrative structures within them that support research commercialization (TTOs, academic departments, techno parks, incubators) (Carayol and Matt, 2004; Audretsch et al., 2005; Dasgupta and David, 1994; Guerrero et al., 2016). The university level explains the efforts by university TTOs to seek out new commercialization opportunities (Siegel et al., 2004, 2007; Clarysse et al., 2004, 2011), facilitate early evaluation of IP rights strategies, exploit infrastructure, stimulate specific venture initiatives and spin-offs (Kenney and Patton, 2005; Wright et al., 2007, 2009), and attract public and private funds (Degroof and Roberts, 2004; Wright et al., 2009; Mosey et al., 2017).

Several successful initiatives to support academic and student entrepreneurship have been implemented in developed countries, for example the Carolina Express Licensing Agreement, University of Missouri and University of Texas, University of California San Diego cases, the Stanford University Network, and others (Mustar et al., 2006; Chapple et al., 2005; Grimaldi et al., 2011). However, universities in many developing and transition countries do not have the same organizational flexibility or high-quality academic entrepreneurship ecosystems.

While the TTO was not an invention of national regulation in transition economies, as with their counterparts in developed countries, the TTOs activities include, but not limited to collecting information on their external partners, registering contracts and protecting the IP (Lockett et al., 2003; Markman et al., 2005b; Lockett and Wright, 2005; Siegel et al., 2007; Perkmann et al., 2013; Huyghe et al., 2016). To illustrate wider TTO's functions in transition economies, we use an example of TTO in a leading regional university in Belarus which includes collection, analysis, creation of a data banks, dissemination and collection of information on research activities of the university and enterprise needs; participation in conferences, seminars, exhibitions; registration and signing contacts between university and researchers as well as industry; implementation of scientific research, exchange of scientific and technical information with national and foreign institutions, provision of information to other technology transfer centres; facilitation of scientific research and development; training scholars and researchers (GSTU, 2017). Two important TTo functions are missing. First, evaluating the invention and deciding whether or not to pursue acquiring a patent (copyright, trademark). This is usually done in negotiation with scientists and potential user of the invention. Second, investing in invention as well as involvement of scientists in the further stages of extensive adaptation of invention (Bradley et al., 2013).

Finally, at the individual level of analysis, we observe the individual characteristics of scientists and incentives that lead scientists to become involved in the commercialization of invention (van Looy et al., 2004; Jain et al., 2009; Guerrero and Urbano, 2014) and facilitating knowledge spillovers (Audretsch, 2014). Scientist's decision-making and a choice of the knowledge transfer model is affected by the ecosystem and university levels, and in particular by their perception of the efficiency of the organizational mechanisms (TTOs, incubators, techno parks and so on) (Kenney and Patton, 2009; Kolympiris and Klein, 2017). The theoretical framework has its roots in the field of Entrepreneurial Theories (ET), investigating the individual attributes and incentives (Kenney and Patton, 2005; Jain et al., 2009; Guerrero and Urbano, 2014) which affect how research is commercialized (Thursby and Thursby, 2004).

2.3. Conceptual model and research hypotheses

The process of research commercialization is multi-dimensional (Fig. 1). Firstly, individual characteristics matter (e.g. position, field of science (basic, applied), proportion of time dedicated to research versus teaching, administration or commercialization, age of scientists, number of research publications) (Aldridge and Audretsch, 2011). Secondly, university environment, institutions (e.g. TTO, Centers for commercialization) and university ownership matter (Algieri et al., 2013). Thirdly, the ecosystem stakeholders influence the entrepreneurial efforts and decision-making on research commercialization (Kenney and Patton, 2009).

A traditional university knowledge transfer model (Siegel et al., 2003) includes the active role of organizational mechanisms in facilitating research commercialization (Bradley et al., 2013). The academic entrepreneurship concludes that organizational mechanisms are not homogeneous across universities (Mowery et al., 2004). Availability of financial resources and practice-oriented staff, a strong business reputation and a number of successfully-completed contracts since the TTO was established (Markman et al., 2005a), are important if TTOs are to market invention and to generate new university start-ups and spin-offs (Meyer, 2003; Siegel et al., 2003).

The prior literature also questions the efficiency of TTOs as facilitators of research commercialization (Siegel et al., 2007; Wright et al., 2007; Kenney and Patton, 2009; Markman et al., 2005b; Aldridge and Audretsch, 2011; Perkmann et al., 2013).

Aldridge and Audretsch (2011), who studied a sample of highly productive scientists in the US found that 30% would choose a 'back-door route' to commercialization. Although the process of direct market commercialization by researchers is complex and requires substantial financial resources, if the TTO is perceived as a barrier then the scientist will attempt to bypass it (Link et al., 2007). Boardman and Ponomariov (2009) applied the university perspective using the national survey of tenured and tenure-track scientists in the US "research intensive" sectors explain, why university scientists choose direct interactions with private companies in commercialization of technology, instead of going a traditional TTO route (Siegel et al., 2004).

In the context of post-socialist economies (Marozau and Guerrero, 2016), TTO face high level of university bureaucracy, absence of economic motivation for TTO staff to commercialize inventions, lack of financial resources to independently market technology, lack of freedom in decision-making to acquire a patent, lack of industry engagement and networking (Kerr and Nanda, 2009; Yegorov, 2009). Altogether these factors create significant organizational filters to knowledge transfer and spillover via TTOs (Siegel et al., 2003; Mowery et al., 2004; Powers and McDougall, 2005; Mustar et al., 2006; Huyghe et al., 2016).

Firstly, and the least of scientist's concern, disclosure of invention puts the novelty of the invention at risk of reengineering and copying by competitors, if TTOs staff starts marketing the invention before the IP protection is sought (Lockett and Wright, 2005; Berman, 2008). The pay-scale in the public sector in transition economies limits the hiring of competent TTO staff and economic motivation (Wright et al., 2008), which increases the risks of non-commercialization or unintended knowledge outflows.

Secondly, high level of bureaucracy and weak IP rights regulation may postpone application for a patent and partner search (Siegel et al., 2003), increasing the time from the discovery to adoption by industry.

Thirdly, complex and restrictive IP rights clauses included by university TTOs lawyers discourage ecosystem stakeholders to collaborate (Freitas et al., 2013). When marketing technology to industry, the TTO should be efficient in navigating conflicts of interests and values between a scientist, university and a private firm (Slaughter and Rhoades, 2004), which rarely happens. Monetary benefits are of great concern to both TTO and a firm, with TTOs having obtained IP rights on patented technology may be hard to negotiate. A widely-used public university practice in transition economies is to take away the IP right from the inventor (Marozau and Guerrero, 2016).

Fourthly, technology adoption typically requires ongoing collaboration with the inventor in order to commercialize technology, which may become difficult as inventor does not hold property rights and may refuse to collaborate. Unlike in the US, when university scientists receive federal grants (Bercovitz et al., 2001), in the transition economies, university receives government grants to serve large publicly-owned enterprises with new technology, where the economic interests of scientists are not considered (Marozau and Guerrero, 2016) and the invention is fully-owned by a university or a national government.

Fifthly, major part of university inventions are nascent in nature and "years away from commercialization" (Bradley et al., 2013: 586). The original invention may be significantly changed at adaptation and utilization stages with or without inventor's involvement in a process, increasing the uncertainty and risk for a TTO.

One of the interesting facts acknowledged in the recent TTO literature (Grimaldi et al., 2011; Siegel and Wessner, 2012; Kolympiris and Klein, 2017) is that universities may have few research results worth commercializing, in particular due to embryonic nature of technology which may require significant further modifications (Bradley et al., 2013).

Finally, for universities in transition economies, TTO is a new phenomenon, because there was little need for mechanisms of knowledge commercialization and IP right protection in a highly centralized planning system with stable production chains (Yegorov, 2009). The regulation aiming to encourage university knowledge transfer has now just begun to develop.

For example, Presidential Decree #59 on the Commercialization of the Results of Scientific and Technological Activities Created at the Expense of Public Funds (Etalonline, 2013), known as the 'Belarusian Bayh-Dole act', tends to confer the IP rights arising from state-funded R &D to universities that receive funding. This legislative initiative is of great importance, since research institutes and university R&D expenditures are funded primarily from the state budget (66%). Meanwhile funding from universities is negligible, accounting for less than 1% (Scienceportal, 2014).

Although TTOs could have created synergistic networks among scientists, industry, university and governments (Bercovitz et al., 2001; Miller et al., 2014), connecting inventors to ecosystem stakeholders that want to adopt university technologies, in transition economies, the implementation of Etzkowitz's (2003) model of knowledge transfer remains limited. A TTO is often perceived by scientists as an additional bureaucratic structure "registering overhead costs" which is "just there" at university (Yegorov, 2009; Marozau and Guerrero, 2016). Scientists in transition economies are likely to choose alternative models of research commercialization (formal and informal) (Boardman and Ponomariov, 2009). We hypothesize:

H1. In transition economies there is a neutral impact of TTOs on university research commercialization.

The traditional model of university knowledge transfer (Siegel et al., 2003, 2004) does not accurately capture the complexities of the process. For example, the marketing of invention does not usually start before the TTO pursues a patent, TTO gauges the industry interest before investing resources into IP protection and further research (Bradley et al., 2013). In troubled transition economies with weak institutions and dominance of public sector in science, Etzkowitz's (2003) and Kenney and Patton's (2009) research commercialization models may not exactly work. First, the ownership is never vested with an inventor to freely choose the commercialization route. Second, inventor as a university employee may not receive a market price when contracting with TTO. Third, loopholes in labour market regulation allow scientists to be full- or part-time employed by a private firm (profit or non-for-profit) as well as perform entrepreneurial activities jointly with industry (e.g. guest talks, paid consulting, technology transfer, copyrights, mentoring, supervising, testing products). In these circumstances an alternative university knowledge transfer model is applied.

To formulate an alternative knowledge transfer model, Heinzl et al. (2013) look into factors that can influence university technology transfer performance, such as research funding, organizational environment, ecosystem stakeholders and the mechanisms of technology transfer. Financial resources to commercialize an invention is one of the biggest issues confronting scientists (Kerr and Nanda, 2009). It is widely acknowledged (Clarysse and Moray, 2004, 2006; Bekkers and Bodas Freitas, 2008; Clarysse et al., 2011; Miller et al., 2014) that the direct industrial funding may provide needed resources (Etzkowitz, 2003). The process starts from commercial and societal needs when firms seek academic resources before contacting a university or scientist to commercialize the technology (Van Rijnsoever et al., 2008).

Except of private industry, who has already identified and use the technology (Aldridge and Audretsch, 2011), other ecosystem stakeholders (e.g. banks and venture capitalists) are unlikely to directly finance university research. This is due to the high risk and asymmetric information on the market value of invention (Kerr and Nanda, 2009; Perkmann et al., 2011) and inability to market invention (Sedaitis, 2000; Leydesdorff et al., 2015).

Empirical precedents for assessing the impact of direct industrial funding of university technology have found that having industry grants increases the involvement of university scientists in rapid technology development and collaboration with scientists working in private companies (Bozeman and Gaughan, 2007), having industry grants increases the likelihood of interacting with private firms in any capacity, including informal knowledge exchanges as well as performance of entrepreneurial activities (Boardman and Ponomariov, 2009), having industry grants increases the favourable attitudes towards university-industry collaboration (Bogler, 1994) as well as academic entrepreneurship activity and publication rates (Van Looy et al., 2004). The links and the degree of industry involvement is the result of individual and mutual choices in a two-sided market of scientists and private firms (Banal-Estañol et al., 2015).

Private companies identify technologies that they wants and directly fund research projects at universities (Van Looy et al., 2004; Perkmann et al., 2011b, 2013). Since industry pays for the research it has an interest in adopting the major research technologies (Wright et al., 2006). Also, firms aim at rapid commercialization and marketing an invention, because the benefits of innovation may depend on how quickly the product is adopted (Siegel et al., 2003, 2004).

In transition countries, direct industrial funding takes place through various channels: outsourcing part of industry research to university scientists (full- or part-time employment); scientist's employment at satellite firms of multinational companies (Zalewska-Kurek et al., 2016) or at headquarters and branches abroad; collaboration with industry scientists via guest talks, paid consulting, technology transfer, including transfer of special competences, access to special data, equipment and infrastructure, funds (Boardman and Ponomariov, 2009).

Direct industrial funding of university research is preferred for scientist in a transition economy for the following reasons. First is commercialization income. Public grants are normally given to low-risk applied research under strict requirements and with public or university ownership of the research outcomes, while direct industrial funding provides additional commercialization income, access to industry financial and technical resources, infrastructure, scientists and data (Melin, 2000; Díez-Vial and Montoro-Sánchez, 2016). Second is control. University ownership systems limits start-ups and spin-offs, as technology is publicly owned and its commercialization is limited (Damsgaard and Thursby, 2013). For example, if the research project is unsuccessful (if a new product does not start selling within three years of its invention), the research investment should be returned to the public sponsor (Etalonline, 2013). Unlike public funding, direct industrial funding has "negotiable" ownership systems on invention (e.g. scientists co-owns new technology). Third is flexibility. Direct industrial funding makes it easier to modify the research results if additional tasks or further adaptation is required (Bradley et al., 2013). This is unlikely with the public grants with limited budgets, strict deadlines on invention and dissemination periods. Fourth is networks. Direct industrial funding opens new possibilities for informal interactions, such as further consulting and collaborative research while further development of technology (Boardman and Ponomariov, 2009). Finally, it is co-ownership on invention. Commercialization agreement is signed between a private company and an inventor (inventor-ownership system) (Perkmann and Walsh, 2010; Hvide and Jones, 2016) and not between a private company and a TTO (university-ownership system), when inventor may not be able to claim IP rights.. In the best possible contract with industry, an inventor will receive a share in royalty on gross revenues or profits.

Political actions aimed at encouraging knowledge transfers using direct industrial funding have recently begun to develop further in transition economies (Bajmócy et al., 2010; Etalonline, 2013). We hypothesize:

H2. In transition economies direct industrial funding facilitates knowledge transfer from university.

2.4. Context of transition countries

We test our hypotheses using individual scientist data from three economies: Belarus, Kazakhstan and Azerbaijan. They are rather peculiar, but representative transition economies. Belarus has a small, open economy and is one of the very few 'soviet'-type countries left, which has recently embarked on significant market reforms and support to information technology sector. Meanwhile, Kazakhstan and Azerbaijan are transition economies largely based on natural resources such as oil and gas. The economic and technological dynamics of these three economies depend to a significant extent on the absorption of new foreign technologies and knowledge (Marozau and Guerrero, 2016). Multinational enterprises have started to be major actors in business R&D with developing linkages to university research.

Since 1991, Belarus, Kazakhstan and Azerbaijan have made greater efforts towards economic openness, trade and investment in new universities, adoption of effective mechanisms for research commercialization and market-based relations between research institutes, universities and enterprises (Yegorov, 2009). They have inherited a relatively well-developed science and technology system of the Soviet Union, however there is still a weak system of economic incentives and research commercialization (Radosevic, 1998).

The economy of these countries is still significantly dominated by large public sector enterprises in machinery, agriculture, oil and gas. Although Belarus has remained much more 'Soviet' than modern Russia, Kazakhstan or Azerbaijan, they are similar with regards to their academic cultures, methods of public support and control over their education and research sectors, government regulatory tools and control over industry and IP rights. Fewer universities compete internationally for publications and international students, with research budgets predominately spent on wages (Yegorov, 2009). Interestingly, unlike universities in Kazakhstan and Azerbaijan, Belarusian universities that were established in the Soviet era have been preserved.

Analysis of knowledge commercialization in these countries as post-Soviet transition economies has important implications, and is relevant to other transition economies in the former Soviet countries (Varblane et al., 2007b).

Overall, the higher education sector is unattractive for young people due to low wages, lack of academic freedom and public (university) ownership on invention. Scientists struggle to commercialize their inventions via a traditional model of university knowledge transfer, aiming to get a part-time employment at multinational firm research labs and collaborate with their scientists. As in other transition countries such as Estonia (Mets, 2009), universities in Belarus, Azerbaijan and Kazakhstan have problems attracting internationally recognized scholars.

There are major differences between research commercialization in Belarus, Azerbaijan and Kazakhstan and in catching-up economies such as Estonia, Hungary, Latvia and Lithuania. The main difference is their ability to learn "how to…" and efficiently transfer technology to industry. Research commercialization models applied in Estonia, Latvia and Lithuania have been tested in the "West" and have become a new emerging institutions (Varblane et al., 2007b). In Estonia, for example, research culture includes establishing and publishing in internationally peer-reviewed journals, grant applications, performance-based distribution of public research funding (Mets, 2009), which does not happen in Belarus, Kazakhstan or Azerbaijan. IP protection and national innovation systems provide more incentives to knowledge transfer, for example in Estonia (Varblane et al., 2007b). Unlike in transition economies, many Estonian universities accepted "the entrepreneurial paradigm of the university in the triple helix of University- Industry-Government relations (Mets, 2006). This demonstrates that universities have begun to encourage the development of spin-off companies (Bray and Lee (2000) and to licence technologies to an entrepreneur (e.g. inventor or external partner) (Phan and Siegel, 2006).

This is unlikely to happen at universities in Belarus, Kazakhstan and Azerbaijan, as TTOs do not establish spin-offs and start-ups, rather they perform an information brokerage function between a university and investors (Lerner, 2005). Collaboration with industry remains the preferred channel of knowledge transfer. Collaboration with other ecosystem stakeholders is limited. First, the government already funds research via national grants with public ownership on invention (not attractive to scientists). Second. angel and venture capital investment is limited in transition economies due to gaps in investor protection. In addition, most of university technologies are at early stage, increasing the risk and uncertainty on investment. Third, collaboration with non-for-profit is negligible and is biased towards foreign grants and academic engagement such as volunteering work without technology transfer. Finally, scientists have little access to foreign universities and institutions outside their countries, including language barrier and lack of networks (Kenney and Patton, 2005). These are the reasons, why research commercialization by scientists in transition economies lags behind their Western counterparts, and that alternative knowledge commercialization models are in place (Kerr and Nanda, 2009; Boardman and Ponomariov, 2009; Kwiek, 2012).

Since existing innovation systems are still unable to link the knowledge creation to knowledge commercialization (Varblane et al., 2007a, 2007b), the authorities made universities rather than scientists responsible for university knowledge transfer. Many universities responded on the call by establishing TTOs. This process was not fully thought through using the role models (Di Gregorio and Shane, 2003; Mustar et al., 2006; Chapple et al., 2005; Powers and McDougall, 2005; Grimaldi et al., 2011; Mosey et al., 2017), when knowledge transfer mechanisms are linked to scientist incentives (Kenney and Patton, 2009; Perkmann et al., 2011b, 2013) facilitating the individual mechanism of the knowledge spillover of entrepreneurship. Traditional universities in Belarus, Kazakhstan and Azerbaijan were reluctant to change their practices, and responded with the development of personal networks with practitioners and research authorities, building large public consortia for collaboration contracts. The model of multilevel interactions between ecosystem stakeholders, university and scientists (Fig. 1) was largely ignored (Degroof and Roberts, 2004; Audretsch, 2014). Consequently, the majority of scientists have been unaware of how to commercialize their research via TTO, and what are the implications of research commercialization: where to find customers and what exactly can and cannot be commercialized? Several legal prosecutions of scientists who informally collaborated with industry have been broadcast in the media in the 2000s, which was not conducive to academic entrepreneurship in a region (Yegorov, 2009). The main obstacles remain an underdeveloped entrepreneurship ecosystem (Grimaldi et al., 2011; Leydesdorff et al., 2015; Theodoraki and Messeghem, 2017), a lack of economic incentives (Guerrero and Urbano, 2014, 2016), and financial resources (Tchalakov et al., 2010).

3. Methodology

3.1. Data, sample selection issues and estimation strategy

The empirical analysis is based on a novel cross-sectional dataset constructed via online survey over three years from November 2015 to August 2017 as the Academic entrepreneurship survey for Belarus, Kazakhstan and Azerbaijan. Participation in the survey was optional. The data collected in this study is the first attempt for generating statistics on university knowledge transfer in transition economies which are not collected by official statistics or by university scientists or TTOs. The online survey generated a comparatively small dataset that could be plagued by a non-response bias or information disclosure bias.

The data has been thoroughly reviewed by the authors. Unique features of the survey include sampling for representativeness at the level of regions in each country (at least one university in each country region and two leading universities in capital-city), university ownership (a balanced number of private/public universities), university size (medium and large) and field of study (at least 4 different faculties within each university) and scientist academic position (junior and senior scientists). The scientific disciplines include mathematics, physics, medicine, chemistry, engineering, agriculture, geosciences, economics and management, sports. The data was collected at 20 universities in three transition countries: Belarus (8 out of 35 universities with approx. 40% of professors' coverage), Kazakhstan (8 out of 61 universities with approx. 30% of professors' coverage) and Azerbaijan (4 out of 28 universities with approx. 44% of professors' coverage).[1] Table A1 in Appendix A provides a list of universities participated in the survey. These countries were selected building upon the societal clusters proposed by the Global Leadership and Organizational Behavior Effectiveness research program (GLOBE) that groups countries on the basis of cultural dimensions and similar institutions (Huyghe et al., 2016).

We started by collecting email and telephone information for the 4705 established scientists via the universities' web-pages by script with the help of the Phython programme. The records could generally be found by typing their full name, university and department. The ensuing e-mail accounts were then collected and registered in the scientist database. Of the 4705 scientists identified and emailed, 2602 responded. This means the initial response rate was 55.30 percent. Only a subsample of individual observations were defined as academically active, and provided information on commercialization income as a share of total income as well as other commercialization activity characteristics. As this might cause a selection bias, regressions based on such survey responses are commonly estimated using a two-stage approach (Heckman, 1979). In this, the subsequent second stage includes a control for unobserved determinants of selection estimated in the first stage (Crépon et al., 1998). Consequently, when an individual does not disclose income from commercialization it may mean they have an income, but do not wish to disclose it, or that they do not know their own income. It would be incorrect to exclude these observations, because the estimation of specific individuals may be biased by the fact that the individual is not properly identified by commercialization income. In the approach used here (Fig. 2) both biases have to be accounted for. To address the disclosure bias we conducted a probit regression on all 2602 individuals identified:

$$\textit{Selection step one}: \; Pr(\textit{Disclosure} = 1 \mid x_i^1) = \Phi(x_i^1 \beta) \tag{1}$$

where x_i^1 contains the variables capturing scientist age, position (associate professor, full professor, researcher) and the type of commercialization activity a scientist is involved in (e.g. honorarium, establishing a spin-off, licencing patents, product sales without spinoffs, public grants and spin-off establishment). We also include country and year fixed effects. Based on this regression, the Inverse Mill's ratio was calculated. It is included in the final outcome regression to control for the disclosure of commercialization information selection bias, also known as independence bias (Herstad and Ebersberger, 2015).

By restricting this analysis to the 424 observations where the individuals all report commercialization income (positive or zero), it is possible to use the additional information available from the survey to estimate the likelihood of an individual to be active or not active in research commercialization. There is a group of scientists which are involved in at least one type of commercialization activity, but report no commercialization. For those observations we define a "commercialization active" bias. We conducted a probit regression on 424 individuals identified:

$$\textit{Selection step two}: \; Pr(\textit{Active} = 1 \mid x_i^2) = \Phi(x_i^2 \beta) \tag{2}$$

where x_i^2 includes characteristics assumed to affect the decision to carry out commercialization activities, including country and year fixed effects. This includes researcher's age, university ownership and the source of research financing (private, government, foreign, university or self-sponsorship) as well as type of external sponsor of research.

Furthermore, financing research should positively influence the propensity to engage in current commercialization activity (Kerr and Nanda, 2009). University ownership (private vs. public) may also influence the decision to engage in research commercialization as well as scientist's age (Crépon et al., 1998). Based on this selection regression a second Inverse Mill's ratio was calculated which was included in the final outcome regression. The correction of two selection biases by means of the three-step model employed here requires two instruments to produce credible estimates. In each stage, at least one variable has to determine selection without affecting the final or subsequent stages (Heckman, 1979; Green, 2002). The results of the selection equations are reported in Table A2 in Appendix A.

In Model 1 (Table A2), scientist age is measured as a natural logarithm as well as licencing patents. Professors and individuals involved in multiple forms of commercialization activity were found to be more likely to disclose their commercialization income.

It is notable no significant impact was detected from other types of commercialization activities on disclosure bias. In Model 2 (Table A2), individuals whose research was financed by foreign and government grants are more likely to be commercially active, while individuals who self-sponsored their research were less likely to be actively commercializing their research.

In order to control for potential bias related to presence (or not) of TTO at university (not all universities had TTOs, see Table A1), we follow Green (2002) procedure to control for it. We include binary variable "TTO at university" which controls whether or not a TTO is established and continuous variable "TTO contracts" which illustrates a number of contracts signed via TTO in our empirical model. Once above variables are included the model will capture decision making on research commercialization by scientists located at universities with and without TTO. Our final sample of 272 researchers consisted of 38 researchers from Azerbaijan, 94 from Belarus and 140 from Kazakhstan.

In most instances, we set up response deadlines and asked university administrators (Deans, Head of Schools, departments and where applicable deputy vice-chancellors) for assistance to disseminate survey questionnaires to increase the response rate. The survey targeted both non-tenured and tenured academic staff (Muscio, 2010; Cunningham

[1] We do not have full data on a sample distribution by university as it was not a mandatory question in the survey. The data does not allow us to identify individuals as neither university name, department name nor university email were mandatory answers. Moreover most researchers and faculty members in the countries in focus have Google or email boxes external to the university. We see it as a way to enable greater confidentiality and avoid disclosure. In order to maintain confidentiality, we left university name and email optional in addition to giving a no-disclosure promise. Very few researchers provided university names, but were more collaborative on Google and email accounts. We thank one anonymous reviewer for drawing our attention to explaining this.

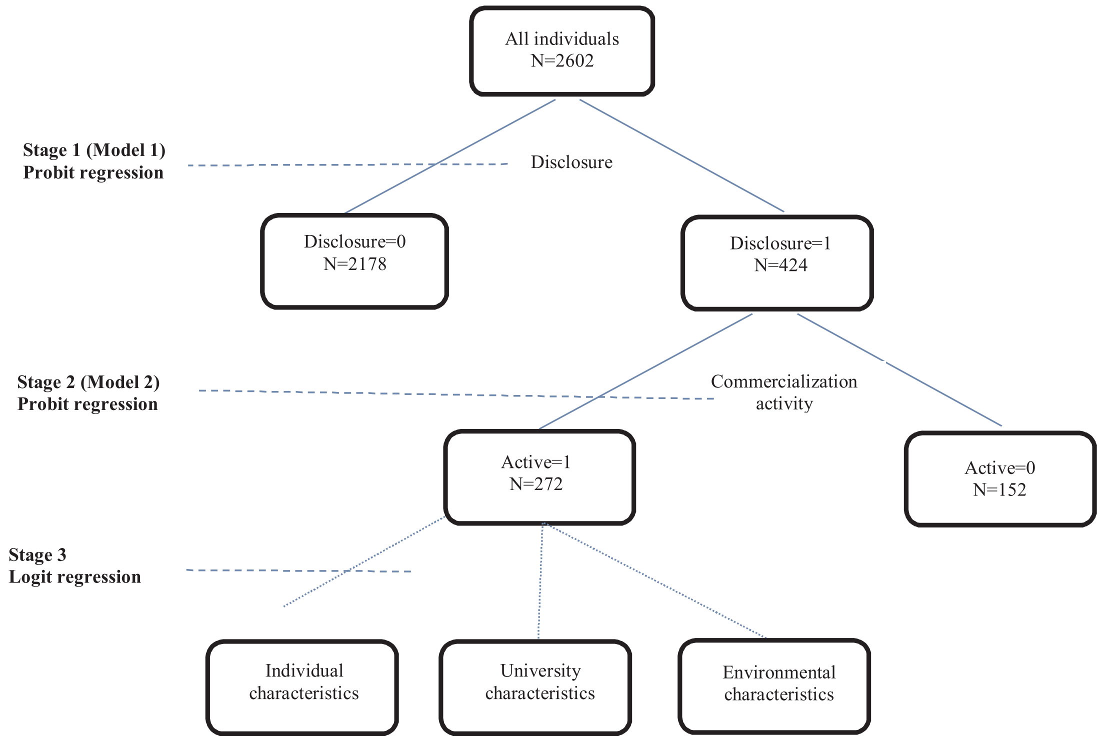

Fig. 2. Estimation strategy.

and Link, 2015).

To support our quantitative approach we used a mixed-methods analysis which involved randomly selecting and face-to face interviewing scientists and TTO managers from the survey sample. We performed 27 face to face interviews (9 in Belarus, 14 in Kazakhstan and 4 in Azerbaijan) with university scientists and TTO managers during April 2016 - September 2017. Interviews were optional and strictly confidential. Appendix B describes the interview sample and Appendix B introduces the interview protocol and eligibility criteria for respondents.

The average age of the respondents was 47.5 years, average experience of research and teaching 22 years, and average commercialization rate being 23 percent in the income. With regards to administrative position and university ownership, 66 percent of respondents were members of the faculty board, 55 percent worked in public universities and 45 percent worked in private universities. Interestingly, only 44 percent of respondents used TTO services or had signed a contract with TTO.

A list of interviewees was created from the individuals who participated in a survey with and left their email willing to stay in touch. These were researchers, managers of business incubators, university technology transfer officers and professors. In addition, a snowball technique was used during the interviews. In this case, the respondents were asked to mention other researchers they knew to provide further opportunities to obtain data. We delineated the population of respondents from these universities based on the following criteria. Firstly, the respondent needed to satisfy the condition of commercializing knowledge and technology created at the university. Secondly, the respondent had to be actively involved in various commercialization activities, with a share of commercialization in total income being positive. Further, the respondent needed to collaborate with at least one ecosystem stakeholder on research commercialization (e.g. university, government, private industry rather than self-sponsoring his(her) research).

We identified scientists in both junior senior positions who were competent to comment, advise and suggest changes in research commercialization policy in these countries. They also advised us on mechanisms and loopholes in the IP rights and academic entrepreneurship ecosystem, where scientists face significant challenges related to co-ownership of invention, engagement with TTOs, private industry, government and adoption of research outcomes. Interviewees has advised which areas needed to be targeted by foreign investors interested in commercializing research outcomes in Belarus, Kazakhstan, Azerbaijan and economies-like.

3.2. Variables

To be included in a sample, all questions related to the variables of interest need to be completed with no missing values. All missing values and non-applicable answers were labelled as missing and therefore excluded from our sample. We proxy research commercialization activity with a share of scientist's annual income from commercialization activities in total income, which is our dependent variable (Wright et al., 2007, 2009; Grimaldi et al., 2011; Siegel and Wright, 2015). The resulting dependent variable was further scaled on the interval [0,1] with the average of 0.14 (14% of annual income from commercialization activity), the lowest share equal zero and the highest share of commercialization equals 0.90 which is 90% of annual income coming from research commercialization. We applied a multi-level approach (Grimaldi et al., 2011; Guerrero and Urbano, 2013; Miller et al., 2014; Theodoraki and Messeghem, 2017) to the process of research commercialization with variables at ecosystem level, university (organizational level), and scientist (individual level).

Our individual level control variables (CVs) build on Wright et al. (2007), Boardman and Ponomariov (2009), Aldridge and Audretsch (2011), Grimaldi et al. (2011), Guerrero and Urbano (2013) and Banal-Estañol et al. (2015) include: researcher's professional and personal characteristics, such as number of works published in the last 5 years; academic position at the university; share of research in total workload; self-sponsorship of research (if any). Individual level has one explanatory variable (EV) which is individual's TTO awareness at university. TTO awareness may reflect the scientist's level of engagement in commercialization. A positive relationship suggests that TTO awareness would increase research commercialization.

Our organizational level CV is university ownership (Aldridge and Audretsch, 2011; Clarysse et al., 2011), which takes a value of one for scientists employed at public universities and zero otherwise. Because they are at least partially financed by the government, public universities are limited in appropriation of IP rights on university research results. For example in Belarus, this has only become possible with adoption of the 'Belarusian Bayh-Dole act' (Etalonline, 2013).

Organizational level has two EVs. First is binary variable equals one if TTO is established at university. Second is the number of contracts signed between a TTO and a scientist, which is a university-level variable. Drawing on Wright et al. (2007, 2008, 2009), Banal-Estañol et al. (2015) and MIT REAP framework (2017) ecosystem level CVs includes direct funding of research by ecosystem stakeholders such as government, industry, risk capital, foreign firms, non-for-profit (NGO) (Siegel et al., 2004; Bradley et al., 2013).

We followed Thursby and Thursby (2004), Grimaldi et al. (2011), Miller et al. (2014), as well as Theodoraki and Messeghem (2017) by asking researchers if they collaborated in their research with any of ecosystem stakeholders (such as industry and professional associations, foreign industry or academia, public institutions or government, non-for-profit or universities).[2] Ecosystem level has one binary EV - direct industrial funding. Our model includes country and year fixed effects. Table 2 illustrates the list of variables at the individual, university and ecosystem levels. These are to be used as explanatory and control variables to test our research hypotheses. Table 3 illustrates a correlation matrix of variables used in our final sample.

3.3. Estimation method

We started our analysis by applying a multilevel generalized linear model to estimate a fractional dependent variable. This was based on reports from individuals observed in the three consecutive waves for Belarus and Kazakhstan, and one wave for Azerbaijan. The sample is rotated, which means that individuals from one wave cannot be tracked in another, and the estimations through a pooled estimation makes distinguishing between temporal or sampling effects unfeasible. The selection of a multilevel estimation approach was based on the model introduced in Fig. 1 with the variables describing individual, university (organizational) and ecosystem characteristics which affect the likelihood of research commercialization.

In a multilevel estimation, sometimes also called a hierarchical, random coefficient was not statistically significant. The data structure in the population was thus not identified as hierarchical (Goldstein, 2011). In other words, a multilevel generalized linear model was not feasible (Goldstein, 2011). This means that neither variation in university characteristics (specification 2 and 3 and 5 and 6, Table A3) nor variation in country characteristics (specification 1 and 4, Table A3) in each survey wave shaped research commercialization (Maas and Hox, 2005). Table A3 offers a robustness check of the multilevel estimation with the distribution of dependent variables (commercialization share) as binomial (specifications 1–3, Table A3) and Bernoulli (specifications 4–6, Table A3). Bearing in mind the issues pointed out by Baum (2008) when modelling proportions as dependent variables, we estimated the generalized logistic model with three-level controls and the fractional dependent variable y_{ijk} defined on the interval [0,1] such that:

$$g[E(y_{ijk})] = \beta_0 + \beta_1 x_{ijk} + \beta_2 z_{ijk} + \beta_3 \lambda_{ijk} + \varepsilon_{ijk} \quad (3)$$

where i is the individual at university j and country k. The explanatory variables are presented by x_{ijk}, control variables are presented by z_{ijk} and the Inverse Mill's ratio for disclosure and commercialization activity bias is λ_{ijk} as described in Crépon et al. (1998). We followed the Heckman (1979) approach to compute two Inverse Mill's ratios (λ_{ijk}) from the Eq. (1) and (2) and including them our final model (3) to control for selection bias. The presence and direction of a selection bias was inferred from the statistical significance and sign of the Mill's ratio coefficients in Eq. (3). Finally, ε_{ijk} is an error term. Eq. (3) includes year and country fixed effects.

4. Results

4.1. TTO and university research commercialization

Table 4 provides the results of our model (3). Neither the establishment of the technology transfer office nor the number of contracts established via the TTO nor TTO awareness had a statistically significant impact on the commercialization share of scientist income, supporting H1 (Table 4, spec. 1–3). The coefficient of TTO awareness ($\beta = 0.605$; $p < 0.12$) is positive, but statistically insignificant at a 10% level (Table 4, specification 3). Predictive Margins with 95% confidence intervals (CIs) in Fig. 3 illustrate a similar level of commercialization share for scientists at universities with and without a TTO. Predictive Margins with 95% CIs in Fig. 4 illustrate a similar level of commercialization share for scientists having different number of commercialization contracts with TTO. For example, scientists who have one or ten contracts with TTO are likely to have a similar level of commercialization income. Predictive Margins with 95% CIs in Fig. 5 illustrate that who were aware or unaware of TTOs existence at university have a similar level of commercialization income.

were helpful in shedding more light on the role of TTOs in university knowledge transfer. Interviewee four (I4) commented, "One of the reasons TTOs are not able to help scholars is the institutional framework which is unfriendly in transition countries" confirming Yegorov (2009). I(4) further laments: "TTOs in Belarus have highly bureaucratized rules and practices and lack expert knowledge, and make it expensive to register contracts and run grants", supporting Link et al.'s (2007) findings. (I1) stated that, "TTOs are becoming university departments that process documents for public funding and grants, and collect substantial shares of financing performing an information broker to government, university and scientists, but not to investors (Lerner, 2005). (I5) adds: "TTO for me equals bureaucracy" (Marozau and Guerrero, 2016). (I7) defended the importance of TTOs at universities, but stated: "You need a person who collaborates with people in the industry and with scientists. But such person is likely to be from a similar background that a researcher to understand how a product works. An entrepreneur definitely needs to be an expert in the product they manufacture. Companies that innovate need people even in marketing and other areas who have PhDs in Physics, or in a very narrow specific field to understand it"(Lockett and Wright, 2005; Berman, 2008). Hiring a competent TTO leader in transition economies is clearly an issue (Wright et al., 2008).

In Azerbaijan the situation with TTOs is concerning. As (I27) commented, "Current state legislation does not even allow universities or research institutions to use international grant funds. In addition, one of the most challenging is the gap in the vision of top management with

[2] As part of the ecosystem we also controlled for the following variables at country level: GDP per capita and population size (millions) from the World Bank development indicators; Global innovation index from the Global innovation index report; patent applications by residents and non-residents per 100,000 residents from the World Bank data and Corruption Perception Index from Transparency International. We used two-year lagged values for these variables to address the issue of endogeneity. Inclusion of these country controls has not changed the coefficient signs, confidence intervals or significance level in our the estimation model (3). Neither has it improved the model specification and goodness of fit, as all macroeconomic indicators were not statistically significant. This means that changes in the entrepreneurship ecosystem related to socioeconomic conditions, innovation and informal institutions do not change the degree of research commercialization by scientist. Our country dummies, which control for country fixed effects, were not statistically significant. We thus decided to keep country controls using the fixed effect approach (Green, 2002). We thank one anonymous reviewer for drawing our attention to this.

Table 2
Description of dependent, independent and control variables.
Source: Academic entrepreneurship survey data for Belarus, Kazakhstan and Azerbaijan (collected 2015, 2016 and 2017).

Variables	Variable description	Mean	St. dev	Min	Max
Individual characteristics					
Commercialization share (DV)	Share of income, funds coming from commercializing research, % (on scale from zero to one)	0.14	0.18	0.00	0.90
Published works	Number of works published in the last 5 years	23.12	16.76	0.00	60.00
Researcher	Research fellow position equals one, zero otherwise	0.13	0.34	0.00	1.00
Ass. Professor	Associate Professor position equals one, zero otherwise	0.36	0.48	0.00	1.00
Research in workload	Share of research in total work 1-(0-25%) to 4 (75-100%)	1.73	0.81	1.00	4.00
Self-sponsor	Research is self-financed equals one, zero otherwise	0.29	0.45	0.00	1.00
TTO awareness	Researcher is aware of a TTO established at university equals one, zero otherwise	0.33	0.47	0.00	1.00
University characteristics					
TTO contracts	Number of contracts signed via TTO	0.46	1.41	0.00	8.00
TTO at university	TTO is established at university, zero otherwise	0.64	0.48	0.00	1.00
Private university	Private university equals one, zero otherwise	0.27	0.44	0.00	1.00
Environmental characteristics					
University sponsor	Research is financed by university equals one, zero otherwise	0.19	0.39	0.00	1.00
Industrial funding	Direct industrial funding of research and technologies) equals one, zero otherwise	0.10	0.29	0.00	1.00
Foreign	External stakeholder: foreign institutions (industry and academia) equals one, zero otherwise	0.25	0.43	0.00	1.00
Industry	External stakeholder: industry and professional associations equals one, zero otherwise	0.18	0.39	0.00	1.00
University	External stakeholder: other academic institutions equals one, zero otherwise	0.38	0.49	0.00	1.00
NGO	External stakeholder: NGOs equals one, zero otherwise	0.12	0.33	0.00	1.00
Public	External stakeholder: public institutions or government equals one, zero otherwise	0.22	0.41	0.00	1.00
Lambda 1	The inverted Mills ratio for disclosure bias	1.58	0.43	0.76	2.85
Lambda 2	The inverted Mills ratio for commercialization active bias	0.27	0.16	0.01	0.60

Note: Number of researchers in final sample: 272.

Table 3
Correlation matrix.
Source: Academic entrepreneurship survey data for Belarus, Kazakhstan and Azerbaijan (collected 2015, 2016, 2017)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Commercialization share	1												
2 Published works	−0.01	1											
3 Researcher	0.08	−0.18*	1										
4 Ass. Professor	−0.03	0.15*	−0.29*	1									
5 Research in workload	0.10	0.18*	0.16*	−0.06	1								
6 TTO contracts	0.05	−0.01	0.27*	0.02	0.11	1							
7 TTO awareness	0.01	0.08	0.11	0.02	0.10	0.40*	1						
8 TTO at university	0.07	0.03	0.16*	0.01	0.02	0.24*	0.53*	1					
9 Private university	−0.04	−0.02	−0.01	−0.04	−0.01	0.02	0.05	0.07	1				
10 University sponsor	−0.04	0.01	−0.07	−0.01	−0.05	−0.13*	0.01	0.02	0.01	1			
11 Industrial funding	0.26*	−0.03	0.09	0.01	−0.03	0.09	0.03	0.01	0.01	−0.11*	1		
12 Self-sponsor	−0.12*	−0.17*	−0.17*	0.13*	−0.10	−0.04	−0.14*	−0.12*	0.21*	−0.06	−0.07	1	
13 Lambda 1	0.12*	0.02	−0.06	0.13*	0.01	0.01	0.04	0.02	0.02	−0.11	0.17*	−0.01	1
14 Lambda 2	−0.13*	−0.19*	−0.07	0.05	−0.14*	−0.08	−0.13*	−0.08	−0.10	0.17*	−0.18*	0.56*	−0.12*

Note: Number of scientists: 272. * −5% statistical significance level of the coefficient. Correlation coefficient are not presented for a set of dummies on collaboration with external stakeholders (industry, foreign institutions, public institutions, NGO and university) to safe space.

university departments as well as departments such as TTOs". This raises the importance of Kenney and Patton's (2009) and Grimaldi et al.'s (2011) argument regarding the creation of a regulation to allow commercialization. Even though there are a number of highly-qualified researchers and human resources at universities, the lack of understanding and vision of the top management prevents successful research commercialization.

(I11) further adds to the efficiency of TTOs in transition economies: "Absolutely no competence at TTO. They do not have experience of working in business or industry. No market intuition, innovative ideas or knowledge of how to commercialize technology" (Link et al., 2007; Wright et al., 2008; Kolympiris and Klein, 2017). Regarding the new generation of TTOs, (I21) adds: "We are the Bekturov Institute of Chemical Sciences in Kazakhstan and commercialize medical chemistry research, development of new to market drugs, with enormous barriers of commercialization in medical practice: no links with pharma private businesses, public and private sponsorship of medical product trials is very low, which directly affects the willingness and interest of medical graduates to work in the field of medical chemistry". (I2) also laments: "TTOs are bureaucrats with [the] decision-making process depending on top university officials and government priorities, not necessarily on what business needs. As a researcher I will go where [the] money [is] when commercializing my research, private business is much of a help". This demonstrates the importance of co-ownership on invention and direct collaboration with industry (Boardman and Ponomariov, 2009)

Scientists reflecting on TTOs bureaucracy and inefficiencies have called for a new generation of TTOs which can develop a practice-based mix of offerings and to become an information broker for potential investors (Lerner, 2005)

(I10) highlights the role of cultural factors, which could not be captured easily captured with the regression model, such as the use of English language in transition economies to communicate to foreigner investors and entrepreneurs. I(20) from Kazakhstan adds on the lack of networking between university and business: "I have worked with a number of business schools, let's put it like that. I've been totally underwhelmed at what I've seen. I've been going to them to market my research and because I wanted a business community. The truth is most businesses know more than most business schools".

Table 4
Generalised logistic model estimation with three-level controls.
Source: Academic entrepreneurship survey data for Belarus, Kazakhstan and Azerbaijan (2015, 2016, 2017)

Model specification	(1)	(2)	(3)
Individual characteristics			
Published works	0.009	0.009	0.008
	(0.01)	(0.01)	(0.01)
Researcher	0.312	0.281	0.356
	(0.56)	(0.56)	(0.56)
Ass. Professor	0.626*	0.609*	0.625*
	(0.35)	(0.35)	(0.36)
Research in workload	−0.342*	−0.358*	−0.363*
	(0.19)	(0.19)	(0.20)
Self-sponsor	−0.599	−0.645	−0.601
	(0.47)	(0.46)	(0.47)
TTO awareness (H1)			***0.605***
			(0.36)
University characteristics			
TTO at University (H1)	***0.413***		
	(0.32)		
TTO contracts (H1)		***0.152***	
		(0.15)	
Private university	−0.213	−0.185	−0.178
	(0.44)	(0.44)	(0.44)
Environmental characteristics			
University sponsor	−0.251	−0.191	−0.253
	(0.39)	(0.39)	(0.39)
Industrial funding (H2)	***1.778****	***1.782****	***1.764****
	(0.91)	***(0.91)***	***(0.90)***
Foreign	−0.07	−0.05	−0.06
	(0.50)	(0.51)	(0.51)
Industry	−0.03	−0.01	−0.04
	(0.54)	(0.54)	(0.55)
University	0.26	0.29	0.32
	(0.47)	(0.47)	(0.48)
NGO	1.46**	1.47**	1.50**
	(0.71)	(0.71)	(0.72)
Public	0.52	0.48	0.51
	(0.48)	(0.48)	(0.49)
The inverse Mills ratio for disclosure bias	−0.651*	−0.658*	−0.663*
	(0.37)	(0.37)	(0.37)
The inverse Mills ratio for commercialization active bias	−2.534*	−2.614*	−2.467*
	(1.49)	(1.49)	(1.49)
country = Belarus	0.910	0.986	0.953
	(0.56)	(0.56)	(0.57)
country = Kazakhstan	0.095	0.180	0.088
	(0.51)	(0.51)	(0.52)
Year 2016	0.862	0.941	0.933
	(0.71)	(0.71)	(0.71)
Year 2017	1.185*	1.305**	1.253*
	(0.66)	(0.66)	(0.65)
Constant	1.703*	1.796*	1.758*
	(0.99)	(0.98)	(0.98)
Number of obs.	272	272	272
LR chi2	41.16	40.73	42.45
Log-likelihood	−130.13	−130.35	−129.49
Pseudo R2	0.13	0.13	0.14

Note: Number of scientists: 272. Reference year = 2015; Reference country = Azerbaijan. ***, ** and * Significance at the 1%, 5% and 10% levels, respectively.

4.2. Direct industrial funding and university research commercialization

Direct industrial funding facilitates knowledge commercialization by scientists (Bogler, 1994; van Looy et al., 2004; Bozeman and Gaughan, 2007).(spec 1–3, Table 4). Fig. 6 illustrates the expected value of research commercialization income under direct industrial funding (private industry).

Scientists who reported their external commercialization partner as industry have significantly higher level of commercialization income, supporting H2. Our findings also supports Kerr and Nanda (2009) and Aldridge and Audretsch (2011) for developed countries, when the lack of industrial funding constrains academic entrepreneurship.

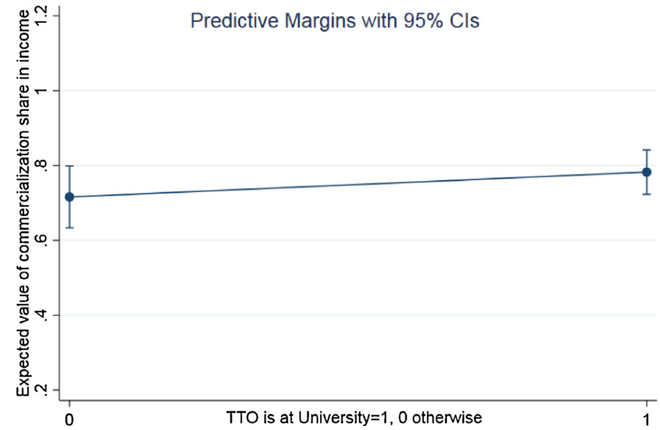

Fig. 3. Predictive Margins with 95% CIs: Expected commercialization rate and TTO establishment at university.

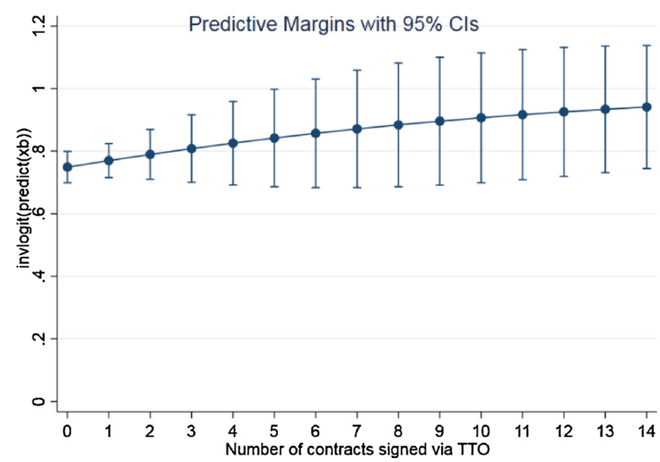

Fig. 4. Predictive Margins with 95% CIs: Expected commercialization rate and number of contracts established via TTO.

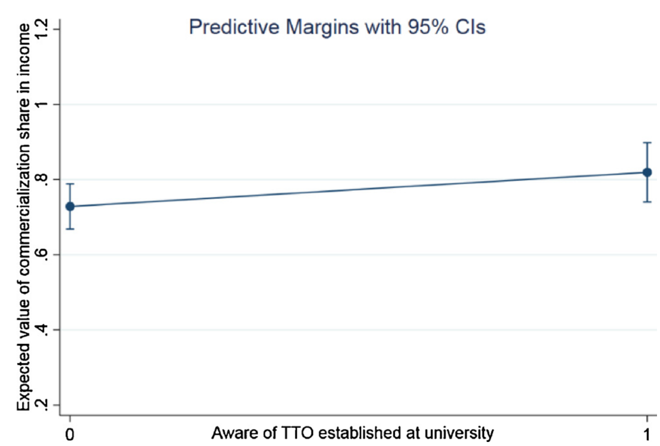

Fig. 5. Predictive Margins with 95% CIs: Expected commercialization rate and TTO awareness.

Our interview results demonstrate that researchers do not consider TTOs to be helpful, and aim to bypass TTOs altogether by directly approaching industry direct (Link et al., 2007; Bozeman and Gaughan, 2007). (I10) stated: "I used to be very well connected to industry in Venezuela and with a few in the US, but here it has been really difficult to approach "the industry" to offer partnership due to the difficulty of communicating in English in much of the power and energy sector, which is my main area…I could, however, connect with foreign

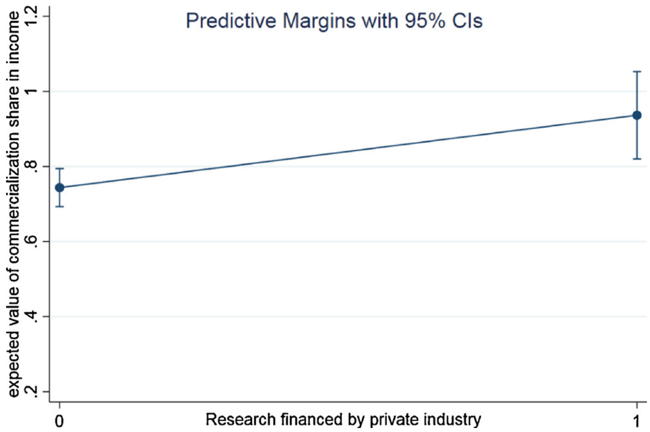

Fig. 6. Predictive Margins with 95% CIs: Expected commercialization rate and direct industrial funding.

industries working in Kazakhstan, interested to adopt technology, but I have noticed they were only interested in providing services". TTOs at university should perform a stronger broker role for investors in marketing invention (Siegel et al., 2004; Cunningham and Link, 2015; O'Kane et al. (2015). As suggested by I(20): "there are commercialization challenges with private industry in Kazakhstan. In my opinion, the level of collaboration between science and industry is at its lowest, and in particular in business and economics". This is puzzling as while university business schools are not engaged in applied research, they could become facilitators of market development and compliment TTOs (Aldridge and Audretsch, 2011; Audretsch, 2014). Several interviewees commented on direct industrial funding in Belarus. (I2) comments: "It is hard to connect to industry if you do not have networks, however those who manage may directly own the invention or share the ownership between a sponsor – private industry and a scientists". (I2) further adds "Direct industrial funding is more attractive here as it is faster, they are open and give more freedom of research and experimentation, they involve you at each step of commercialization and pay royalty" (Melin, 2000; Slaughter and Rhoades, 2004; Damsgaard and Thursby, 2013). Our interviews confirm that scientists support the "Professor Privilege" –type system (Hvide and Jones, 2016) and wish it to be adopted in transition economies.

4.3. Other factors and university research commercialization

At the individual level of university knowledge transfer model, prioritizing research over teaching and commercialization results in a lower commercialization income ($\beta = -0.342$–0.363; $p < 0.10$), while being an associate professor increases commercialization income ($\beta = 0.609$–0.626; $p < 0.05$) (Aldridge and Audretsch, 2011). Neither self-sponsoring research nor publication record is associated with research commercialization income, which contrast negative association found by Boardman and Ponomariov (2009). High number of publications may not necessarily correspond to high-quality research in a transition context as most of publications target national and not international peer-reviewed journals.

At the organizational level, university ownership is not associated with research commercialization income. At the ecosystem level, university funding research does not change research commercialization income. Research funding by public institutions, foreign institutions and professional associations as well as academic partner institutions (outside the university) is not associated with research commercialization income. Collaboration with non-for-profits increases commercialization income ($\beta = 1.46$–1.50; $p < 0.05$), however, this type of collaboration usually includes paid consultancy and volunteering work, and is not associated with technology transfer to non-for-profit (Bercovitz et al., 2001)..

Ecosystem-level formal and informal institutions in Belarus, Kazakhstan and Azerbaijan were similar to each other in their impact on research commercialization income of scientists. An average scientist's commercialization income in 2017 was higher than in 2015. Inverse Mill's ratios for disclosure bias and commercialization active are negative and statistically significant. This demonstrates that respondents who did not answer the question on commercialization and were not included in our final sample were less likely to participate in commercialization activity and receive an income.

5. Discussion

Unlike factors which influence research commercialization in developed economies (Chapple et al., 2005; Mustar et al., 2006; Grimaldi et al., 2011; Heinzl et al., 2013; Bradley et al., 2013) forged through social capital measures and experience gained by serving on an advisory board, in the transition context they do not seem to play an important role. At the same time aspects of human capital such as academic position as well as personal characteristics of scientists such as age, publication record have little or no effect on commercialization income, either in the US (Aldridge and Audretsch, 2011) or in transition countries.

According to the existing literature (Thursby and Thursby, 2004; Perkmann et al., 2013; Guerrero and Urbano, 2014, 2017) and in case of the troubled transition economies (Marozau and Guerrero, 2016), we found that the universities' TTOs are limited in their legal and resource ability to commercialize university research (Perkmann et al., 2013). Scientists at universities often treat invention as a "public good" (Slaughter and Rhoades, 2004), hence the detect involvement of a scientist in a start-up or spin-off is unlikely. In contrast, private industry funds research it has already identified to have high potential for commercialization. Since private industry pays for the research it has an interest in adopting it as well as maintaining the legal ownership of research outcomes (Boardman and Ponomariov, 2009). U

Our finding demonstrates that direct industrial funding is the most efficient route of research commercialization by scientists as compared to disclosure, marketing and adaptation of technology via TTOs. We contend that TTO activity and direct industrial funding are not two successive steps, but may perform as two alternative models of knowledge transfer. This is an unexpected and interesting finding, which emphasizes the role of inventor-ownership on research outcomes in transition economies. The implementation of inventor-ownership mechanism in transition economies is challenging. This will require legal changes (e.g. IP regulation, co-ownership), creating university environment which is supportive to entrepreneurial activities (e.g. adjustment in teaching load, academic leadership and citizenship, funding conferences, academic visits, guest lectures, applied research and dissemination activities) (Kenney and Goe, 2004), in particular, TTOs should be granted greater independence from university and their leaders to be given more economic incentives to become a conduit of knowledge transfer.

To date, TTOs have become neither facilitators nor promoters of knowledge transfer and knowledge spillover from universities. This challenges the legitimacy of TTOs (O'Kane et al., 2015) as centres of knowledge transfer. Kenney and Patton (2009) found the system under which universities maintain the legal ownership of inventions is less than optimal in terms of economic efficiency and in advancing the private interests of commercialization. Our finding confirms it for transition economies.

We propose three alternatives that would address the current lack of scientists' engagement in research commercialization in transition contexts.

Our first proposal is to vest ownership with the inventor in a spirit of the "Professor Privilege" system. Investors should be free to contract with the university TTO or any other entity outside the university to support research commercialization. Inventor-ownership system was suggested by Kenney and Patton (2009) and in recent works by Czarnitzki et al. (2015, 2016) who found that transition from an inventor-ownership to a university-ownership model decreased both the volume and quality of patented inventions by university professors. Hvide and Jones (2016) found that the abolishment of" Professor's Privilege" in Norway led to about a 50% drop in the rate of start-ups by university researchers. Policy makers who presumed that costs and risks of patenting and starting a business were too high for individual inventors appeared to be wrong.

Our second proposal is to sponsor open access to university research through public funds, without an exclusive right of a public sponsor, or a university, on research results in any sector and any university type. All inventions will be further contracted by the TTO if the establishment of a legal relationship to further expand and validate the inventions is required by industry. It is also important that all inventions should be licensed freely and non-exclusively. Unless sponsored directly by private industry, neither universities TTO nor other public sponsor may hold exclusive ownership of inventions (Powers and McDougall, 2005; Audretsch, 2014; Shu et al., 2014).

Our third proposal is to support TTO's brokerage between junior university scientists and industry (Perkmann et al., 2013). Junior scientists have less experience in marketing technology to private industry and work with early stage technologies may benefit most by disclosing their inventions to TTOs as the earlier stage of technology development (Lerner, 2005).

Interviewee (I20) contributed to this discussion: “We need a commercialization platform to engage researchers right through the university to industry. This is private industry which needs to dictate [to] TTOs what problems need to be solved and what would they like to improve”. These measures will enhance participation of ecosystem stakeholders and TTOs in knowledge transfer. Various crowdfunding platforms and angel investor funds have been established in collaboration with the business schools in developed economies (Guerrero and Urbano, 2012, 2014; Belitski and Heron, 2017). If current structures cannot be created with the current competences on the basis of TTOs in transition economies, scientists, in particular more mature and with late-stage technologies will continue to bypass TTOs (Link et al., 2007). A new generation of TTOs should be integrated within business schools structures with private ownership on invention in case of successful fundraising. Finally, the effect of university support mechanisms should be more decisive (Kenney and Goe, 2004; Kwiek, 2012). “What makes a die-hard academic entrepreneur?” with 15 years overview of the academic entrepreneurship and knowledge transfer literature, the answer is very different to scientist entrepreneurs in transition economies.

6. Conclusions

By asking scientists rather than university TTOs (Caldera and Debande, 2010) about the entrepreneurial activities they engage in and their commercialization income, a clear picture emerges for the research commercialization in transition economies. Firstly, a number of indications suggest that there is no relationship between the establishment of TTOs, TTO awareness, the number of contracts signed via a TTO and the extent of research commercialization. The former is not associated with individual characteristics such as scientist age, research output and quality or the self-sponsorship of research. Secondly, direct industrial funding is an effective conduit of knowledge transfer and knowledge spillover from universities, which may function as a substitute for public and angel finances. It is important that ownership is shared between an inventor and industry. Thirdly, the extent of research commercialization is less organisationally embedded and more ecosystem embedded with direct industrial funding plays the leading role in research commercialization (Boardman and Ponomariov, 2009; Grimaldi et al., 2011; Miller et al., 2014; Acs et al., 2017).

The empirical results from this study also suggest that more scientists engage in research commercialization in transition economies than in the US (Aldridge and Audretsch, 2011); however, only 13 percent of them are paid for knowledge transfers. This study makes the following contributions to academic entrepreneurship, entrepreneurship ecosystems and the KSTE literatures.

First, adopting the TTO perspective of the KSTE and the stakeholder perspective to entrepreneurship ecosystem framework, we investigate research commercialization by scientists in transition economies controlling for individual, university and ecosystem characteristics. The empirical results suggest, that commercialization income does not exactly mirror what has been found in the literature on academic entrepreneurship in developed economies (Wright et al., 2006, 2007; Kenney and Patton, 2005, 2009; Aldridge and Audretsch, 2011; Perkmann et al., 2011a, 2013).

Secondly, we develop a multi-level model of university research commercialization, which jointly examined the role of TTOs and direct industrial funding capital as a conduit of knowledge transfer from university in transition countries.

Thirdly, using unique primary data on scientists' entrepreneurial activity in three transition economies and controlling for various selection biases, this study provides important evidence for users / investors of academic research in transition economies. We demonstrate that university TTO, unlike direct industrial funding, has not yet become a conduit for knowledge transfer and spillover (Audretsch, 2014).

Responding to a call in the academic entrepreneurship literature (Kenney and Patton, 2009; Grimaldi et al., 2011; Aldridge and Audretsch, 2011), this study identifies the determinants of university research commercialization across a broad spectrum of scientific fields, sizes, types of universities and in a different socioeconomic context. Whether this finding holds across broader groups of developing and transition economies as well as across more specific scientific fields and ecosystem stakeholders is an important issue that will be addressed in future research.

Subsequent research needs to identify the prevalence and multi-level determinants (Perkmann et al., 2013; Guerrero and Urbano, 2013) of a variety of research commercialization models, such as establishing a spin-off, corporate entrepreneurship, paid consultancy and other (Muscio, 2010; Siegel et al., 2007; Kenney and Patton, 2009; Abreu et al., 2016; Kolympiris and Klein, 2017). What particular organizational and ecosystem characteristics as well as scientist's capabilities that facilitate interactions with the industry, foreign firms, government and TTOs? Given a very limited functions of TTOs in transition economies, it is unlikely we can expect any substantial effect of TTO activity on the valorization of research results. Implementation of the multi-level academic entrepreneurship ecosystem framework in future research (Perkmann et al., 2013; Acs et al., 2017) could be an answer to how research commercialization could be better facilitated by a variety of entrepreneurial ecosystem actors. It is also important to find an entrepreneurship ecosystem locus (city, region, country) with characteristics which are strongly associated with scientists' decision-making to commercialize research.

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Appendix A. Supplementary data

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