Technological Forecasting & Social Change 103 (2016) 34–46

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Addressing barriers to eco-innovation: Exploring the finance mobilisation functions of institutional innovation intermediaries

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ARTICLE INFO

Article history:
Received 3 October 2014
Received in revised form 5 August 2015
Accepted 1 October 2015
Available online 28 November 2015

Keywords:
Intermediaries
R&D support
Innovation barriers
Thin markets
Innovation finance
Innovation policy
Information asymmetries

ABSTRACT

This research article explores the role of institutional innovation intermediaries in accelerating the commercialisation of (clean) technologies. Drawing on the finance and innovation intermediaries literatures, we show that financial barriers to eco-innovation can be partly overcome by particular functions of institutional innovation intermediaries; this in turn mobilises private finance along the innovation process. Therefore, we empirically evaluate the roles and instruments of institutional innovation intermediaries (innovation intermediation, policy support, public–private cooperation, financial instruments). Our contribution intersects both the finance and the innovation systems literature by exploring the finance mobilisation functions of institutional innovation intermediaries to address barriers to eco-innovation along the innovation process.

1. Introduction

The ongoing debate about how to mitigate climate change has encouraged policymakers to initiate R&D for eco-innovations. The aim of these initiatives is twofold: firstly, to reduce carbon emissions and, secondly, to foster long-term economic green growth (Strand and Toman, 2010; OECD, 2009). However, complex system failures occur surrounding the commercialisation of eco-innovations[1] due to high uncertainty, the absence of carbon markets and the resulting technological lock-in (Leitner et al. 2010). Many firms and research institutes invent technologies that are eventually not introduced to the market because of underinvestment in R&D or other (finance-related) barriers such as imperfect capital markets, difficult scalability, asset intensity, the absence of complementary assets such as infrastructure and an inadequate regulatory environment (Marcus et al., 2013; Kenney and Hargadon, 2012; Olmos et al., 2012; Mathews et al., 2010; Haley and Schuler, 2011). The incorporation of the finance perspective at an early stage, including the cooperation of innovative firms and research institutes with financiers, could leverage public and private funds more effectively, enhance innovation activity and finally accelerate the commercialisation and diffusion process. Consequently, especially for climate change-related eco-innovation, there is huge potential in connecting public support with private finance, because of the persistent information asymmetries between innovators and financiers (Mowery et al., 2010).

Key actors in the innovation process include institutional (i.e. government-affiliated) intermediaries that play a crucial role in establishing and governing a closer collaboration and in fostering knowledge flows between innovators and financiers to reduce information asymmetries and uncertainty (Kivimaa, 2014; Howells, 2006; Hoppe and Ozdenoren, 2005; Moore et al., 2012a). In recent years, a lot of work has been done on innovation intermediaries (Howells, 2006; Katzy et al., 2013; Klerkx et al., 2015; Klerkx and Leeuwis, 2009; van Lente et al., 2003; Yusuf, 2008), resulting in conceptual and qualitative evidence that innovation intermediaries at the intersection of public and private R&D and commercialisation have beneficial effects (Kivimaa, 2014; Klerkx and Leeuwis, 2009; Yusuf, 2008; van Lente et al., 2003). More specifically, previous research has looked at their functions (Hoppe and Ozdenoren, 2005; Howells, 2006), how innovation intermediaries enhance user–producer interactions and demand articulation (Boon et al., 2008, 2011), their role in commercialising research (Yusuf, 2008), their interaction with the policy environment (Klerkx and Leeuwis, 2009) and their broader role with regard to stimulating a transition towards sustainability (Kivimaa, 2014; Moore et al., 2012b; van Lente et al., 2003).

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[1] On the basis of previous literature (Horbach et al., 2012; Foxon and Pearson, 2008; Rennings, 2000), this article adopts the following definition of eco-innovations: the invention, commercialisation and diffusion of clean technologies that reduce carbon emissions and/or other environmentally negative impacts and thus contribute to sustainability.

http://dx.doi.org/10.1016/j.techfore.2015.10.001
0040-1625/

Although it has been recognised that innovation intermediaries help in mobilising several resources for innovation, the previous literature on innovation intermediaries has not investigated the mobilisation of finance for innovation. If previously separated literature streams on financing innovation and innovation intermediaries are drawn together, it becomes apparent that innovation intermediaries could play an important role in addressing financial barriers to eco-innovation along the innovation cycle, as they hold a critical position between market actors and government (Howells, 2006; Kivimaa, 2014; Yusuf, 2008; Mowery et al., 2010). As there has been no systematic evaluation of institutional innovation intermediary roles and functions to address barriers to eco-innovation and correspondingly mobilise private finance, our paper seeks to address this gap by analysing the following research question: *How do institutional innovation intermediaries address the complex set of barriers surrounding (eco-)innovation especially from R&D to commercialisation, with an emphasis on mobilisation of finance*?

We address this question in the context of eco-innovation, as innovation system problems such as thin markets for finance, information asymmetries and failing markets for technologies are more pronounced there, but we also believe it to be of relevance for innovation in general. We present qualitative in-depth evidence, exploring institutional innovation intermediaries' finance mobilisation functions and roles. The article is structured as follows. Section 2 outlines the theoretical underpinnings and integrates the streams of literature on innovation finance and innovation intermediaries. Section 3 sketches the methodological approach taken to assess the role of intermediaries and to evaluate their finance mobilisation functions. Section 4 presents the findings, and Section 5 interrogates these findings with theory to draw conclusions and to derive policy implications in Section 6.

2. Theoretical background

2.1. Financing R&D and innovation

Scholars consider financiers as crucial to support the commercialisation and diffusion of new, clean and low-carbon technologies generated by eco-innovation processes (Hekkert and Negro, 2009; Hekkert et al., 2007; Perez, 2002; Schumpeter, 1939), and several researchers have highlighted an underinvestment in R&D as a market failure for innovation activity in the early stages (Hall and Lerner, 2010; Hall, 2002; Myers and Majluf, 1984): Firstly, financiers, from their market logic perspective, cannot evaluate the quality of new research because of its highly uncertain nature (Jaffe et al., 2005; Akerlof, 1970; Arrow, 1962). Possible gains from R&D cannot be fully appropriated by the firm because of knowledge spill-overs, i.e. the social returns are higher than the private return appropriated (Jaffe et al., 2005; Griliches, 1992). Secondly, imperfections in capital markets affect firms' fundraising capability (Hall, 2002). Financing innovation and its related market failure are clearly an issue within the framework of innovation systems, but the broad question of financing innovation activity has not been treated holistically, although several authors have indicated that the financial innovation system underlying national and technological innovation systems is a significant driver of innovation activity and should therefore include well-coordinated policies (Dahlstrand and Cetindamar, 2000; O'Sullivan, 2006; Perez, 2013; Wonglimpiyarat, 2011). Private finance is highlighted as a critical factor in particular in the context of a transition towards eco-innovation (Leete et al., 2013; Mathews et al., 2010; Moore et al., 2012a; Perez, 2013).

Within the innovation policy mix that is created to enable this transition, different policy instruments are implemented (see Borrás and Edquist, 2013 for a generic overview of innovation policy instruments), of which economic transfers comprising different forms of finance is one. Different phases of the innovation process, i.e. basic and applied R&D, demonstration and commercialisation, pre-commercial phases, niche-market and the supported commercial as well as the fully commercial phase call for different forms of finance, the so-called finance chain of innovation (Auerswald and Branscomb, 2003). In the basic and applied R&D phases, governments use subsidies and grants to address underinvestment in R&D that is risky due to intangibility and the limited extent to which it can be appropriated in terms of tangible returns to the firm (Link and Scott, 2010; Dahlstrand and Cetindamar, 2000).

When the commercialisation phases (demonstration, pre-commercial, niche-market and supported commercial) are reached – when 'investment readiness' is proved by signalling the quality of the business proposition linked to the emerging technology – external financiers such as business angels and venture capitalists (VCs) start financing (Mason & Harrison 2001). Informed financiers (i.e. so-called competent VCs – Dahlstrand and Cetindamar, 2000) try to overcome underlying information asymmetries and other barriers, such as a lack of managerial talent, marketing capabilities or networks, thereby reducing the monitoring and moral hazard problems (Da Rin et al., 2006; Repullo and Suarez, 2000; Holmstrom and Tirole, 1997). However, VCs have several shortcomings, such as the need to have a well-functioning equity market and a focus upon only certain industries at a time, that make them unsuitable for investing in infrastructure, larger R&D projects or asset-heavy firms and projects (Hall and Lerner, 2010; Oakey, 2003; Hall, 2002; Kenney and Hargadon, 2012). In addition, private equity, mezzanine and bank finance are often not available because of lack of collateral or the overall level of risk relating to the technologies and the institutional environment (Ughetto, 2007, 2010). More mature firms often rely on internal funds; however, as commercial viability is often uncertain, these companies refrain from commercialisation activities. In many cases, this leaves structural holes (e.g. known as the 'valley of death') in the commercialisation phase, since private equity, many VCs and credit financiers are often unable to seamlessly invest either in companies that reach the end of the public R&D support phase or in complementary assets such as the infrastructure required for commercialisation (Auerswald and Branscomb, 2003). Consequently, this can lead to thin financial markets as difficulties arise in the supply of, and demand for, finance. Simply increasing demand or supply is not sufficient, as coordination problems often arise between innovators (e.g. entrepreneurs), financiers and government (Nightingale et al., 2009; Dahlstrand and Cetindamar, 2000). Policymakers could therefore systematically strengthen the market-demand side by establishing public procurement programmes or public–private research partnerships in order to strengthen the technological capability to support the supply side (Audretsch and Lehmann, 2004; Auerswald and Branscomb, 2003; Edquist and Zabala-Iturriagagoitia, 2012; Hargadon, 2010; Link and Scott, 2010).

In later stages of the innovation cycle (supported commercial and fully commercial), (clean) technologies face regulatory risks, flawed market pricing mechanisms or policy coordination failures (Weber and Rohracher, 2012; Haley and Schuler, 2011; Foxon et al., 2005). In this situation, governments could provide incentives to the financial sector and play a catalytic role in providing risk capital. This could be done by regulating certain industries, setting up institutions to make investments more profitable (Borrás and Edquist, 2013; Wonglimpiyarat, 2011) or using direct instruments such as public procurement for innovation (Edler and Georghiou, 2007; Edquist and Zabala-Iturriagagoitia, 2012; Guerzoni and Raiteri, 2015). An overview of instruments used to finance innovation is provided in Table 1.

2.2. The role of intermediaries in addressing financial barriers

One way to address the obstacles and structural financial barriers in the innovation cycle (see Table 1) is to have intermediaries between different actors (Howells, 2006). These actors intermediate knowledge, technologies and finance, which is crucial for advancing markets (Stewart and Hyysalo, 2008; Boon et al., 2008; Howells, 2006; Hoppe and Ozdenoren, 2005). Howells (2006, p.720) defines an innovation intermediary as '*an organisation or body that acts an agent or broker in*

Table 1
Overview of barriers to innovation and financing instruments.

Phase in the innovation cycle	Barriers	Instrument	References
Basic and applied R&D	Intangibility and limited appropriability (knowledge spill-overs)	Subsidies, grants	Meuleman and De Maeseneire (2012); Kleer (2010)
	Underinvestment in R&D	Tax credits	Czarnitzki et al. (2011); Hall and Lerner (2010)
Demonstration and pre-commercial	Capital intensity Scalability	Mobilise private finance (business angels, venture capitalists)	Kenney and Hargadon (2012); Hendry et al. (2010)
	Economic/technological/institutional lock-in	STI policy Regulation	Foxon and Pearson (2008); Klein Woolthuis et al. (2005); Rennings (2000)
	Infrastructure	Public procurement Public–private partnerships	Foxon and Pearson (2008); Köhler et al. (2010)
	Market/demand articulation	Public procurement Effective coordination of demand-side policies	Edquist and Zabala-Iturriagagoitia (2012); Hargadon (2010); Edler and Georghiou (2007)
Niche-market and supported commercial	No venture capitalists Flawed pricing mechanisms	Strategic research partnerships (e.g. SBIR, ATP, ARPA-E)	Audretsch and Lehmann (2004); Link and Scott (2010); Auerswald and Branscomb (2003)
Fully commercial	Regulatory risks Policy coordination and reflexivity failures	Mobilise private finance (Private equity, banks, mezzanine, project finance)	Weber and Rohracher (2012); Haley and Schuler (2011); Foxon et al. (2005)

Note: ARPA-E: Advanced Research Projects Agency–Energy; SBIR: Small Business Innovation Research; ATP: Advanced Technology Programme (refers to cooperative innovation programmes in the US).

any aspect of the innovation process between two or more parties. Such intermediary activities include: *helping to provide information about potential collaborators*; *brokering a transaction between two or more parties*; *acting as a mediator*, *or go-between*, *bodies or organisations that are already collaborating*; *and helping find advice*, *funding and support for the innovation outcomes of such collaborations*'. Throughout this paper, we focus on innovation intermediary functions that relate to finance, since the mobilisation of financial resources is considered a key function of innovation systems whose failure often hinders technologies from being developed and deployed (Jacobsson and Karltorp, 2013; Jacobsson and Bergek, 2011; Bergek et al., 2008). This broad finance mobilisation function is further differentiated along the innovation cycle, as innovation intermediaries may execute different, more specific finance mobilisation functions and connect to different finance sources along the different innovation phases (see Table 2).

During the basic and applied R&D phases, which exhibit high technological and market uncertainty and a general underinvestment in R&D, innovation intermediaries help to find new sources of capital for researchers, such as R&D programmes, research grants and subsidies. Especially in public–private partnership (PPP) constellations concerning the development of complex innovations such as eco-innovations with a highly uncertain outcome, a more active management approach is needed to bring the necessary resources and stakeholders together and reduce development time and costs (Yaqub and Nightingale, 2012). Prior research also points out the relevance of selecting the most suitable finance mechanisms for each type of project (e.g. subsidy, revolving fund, loan and so forth) (Eickelpasch and Fritsch, 2005). The goals of the research efforts need to be aligned with the selection process of supported firms and corresponding financial support mechanisms (Santamaría et al., 2010). In this regard, intermediaries might also be capable of sending signals to certify the quality of research (Yusuf, 2008; Howells, 2006).

During the demonstration and pre-commercial phases, eco-innovations exhibit high capital intensity, challenging scalability, a lack of complementary assets such as infrastructure and demand articulation problems. Here, innovation intermediaries are involved in the distribution of R&D grants and demonstration support (Samila and Sorenson, 2010; Brown and Hendry, 2009). Additionally, they might coordinate public-procurement programmes in order to increase demand. Innovation intermediaries may also engage in PPPs between private financiers, government agencies and inventors or start-ups, as seen in SBIR (Small Business Innovation Research) and ATP (Advanced Technology Programme) projects. Evaluation of such PPPs revealed mixed evidence with regard to the commercialisation success of the participating firms (Link and Scott, 2010; Audretsch et al., 2002; Chang et al.,

Table 2
Overview of financing instruments to which innovation intermediaries may connect.

Category	Instrument	Corresponding phase in the innovation cycle	References
Direct	Subsidies, grants	Basic and applied R&D Demonstration and pre-commercial Niche-market and supported commercial	Kivimaa (2014); Howells (2006)
	Tax credits	Basic and applied R&D	Howells (2006)
	Public procurement or Production support measures	Demonstration and pre-commercial Niche-market and supported commercial	Kivimaa (2014)
	Mobilise private finance (business angels, venture capitalists)/improving positive expectations of future market opportunities	Demonstration and pre-commercial Niche-market and supported commercial	Presented as potential role, but not further elaborated upon by Kivimaa (2014); Yusuf (2008); Howells (2006)
Indirect	Support for regulation	Niche-market and supported commercial Fully commercial	Kivimaa (2014); van Lente et al. (2003)
	Support for science, technology and innovation (STI) policy	Niche-market and supported commercial Fully commercial	Klerkx and Leeuwis (2009); van Lente et al. (2003)
	Strategic research partnerships (e.g. SBIR, ATP, ARPA-E)	Basic and applied R&D Demonstration and pre-commercial	Kivimaa (2014); Klerkx and Leeuwis (2009); Yusuf (2008)
	Mobilise private finance (private equity, banks, mezzanine)/Improving positive expectations of future market opportunities	Niche-market and supported commercial Fully commercial	Presented as potential role, but not further elaborated upon by Kivimaa (2014); Yusuf (2008); Howells (2006)

Note: ARPA-E: Advanced Research Projects Agency–Energy; SBIR: Small Business Innovation Research; ATP: Advanced Technology Programme (refers to cooperative innovation programmes in the US).

2002; Lerner, 1999). Clearly, these PPP programmes address the under-investment in R&D and commercialisation; this confirms that firms need financial support to scale up their operations when they have passed the seed and invention stage (Cooper, 2003). Put alternatively, government or government-affiliated entities such as intermediaries 'thicken up thin financial markets' for early stage innovations (Mazzucato, 2013; Link and Scott, 2010; Nightingale et al., 2009).

In the niche-market, supported commercial and fully commercial phases, the role of innovation intermediaries is less visible as the technology matures. However, regulatory risks and the provision of complementary assets need to be navigated to fully deploy technologies. Thus, a relevant function during commercialisation and diffusion is the mitigation of uncertainty and risk between firms or research institutes and potential financiers, as the latter are unable to access either the potential markets for the application of the novel technologies or their surrounding institutional environment (regulation and science, technology and innovation [STI] policy) (Kenney and Hargadon, 2012; Marcus et al., 2013). Intermediaries evaluate commercial value and reduce uncertainty by bringing potential innovators and market participants together (i.e. the benefits that lead to a market equilibrium outweigh the costs incurred by the intermediating organisation) (Hoppe and Ozdenoren, 2005).

Kivimaa (2014) highlights the specific role and utility of government-affiliated or institutional innovation intermediaries to address (systemic) failures along the innovation cycle. These are ideally positioned for this, because they intermediate knowledge and finance between public (research organisations, government) and private actors (such as firms) in the innovation system, translating policy objectives on stimulating eco-innovation on the one hand and requests or demands from the private side on the other hand (Klerkx and Leeuwis, 2009). Institutional innovation intermediaries are affiliated with, and generally funded by, policy bodies (i.e. ministries) whose aim is to advance technologies but also to foster markets and generate subsequent private investments after the R&D support phase. In order to obtain a legitimate position as a broker in a network of different public and private actors, institutional innovation intermediaries, it has been argued, should have some degree of independence in terms of the types of projects they support and the relationships they broker (Klerkx and Leeuwis, 2009). Because of their affiliation with policy bodies, institutional innovation intermediaries may have limited independence, as conflicts of interest between the public bodies to which they are affiliated and the private entities could arise (Klerkx and Leeuwis, 2009; Kivimaa, 2014). Thus, as Klerkx and Leeuwis (2009) argue, institutional innovation intermediaries should have a degree of freedom as to what kinds of eco-innovation they support and whom they engage as partners in the innovation process, and they should also be able to deviate from policy lines in view of the need for the 'creative destruction' of existing systems that may be required for system innovation (Moore et al., 2012b; van Lente et al., 2003).

3. Methodology

3.1. Research approach

To develop an empirically based perspective in the context of the above-reviewed literature, an exploratory, inductive methodology was applied, since there is limited empirical understanding of the phenomenon and a small number of cases available to further build and refine theory (Eisenhardt, 1989; Yin, 2009). Our approach consists of a multiple case study design (six cases of project-managing organisations fulfilling the institutional intermediary role) that generates in-depth knowledge about a complex phenomenon (Patton, 2002). The theoretical understanding (see Sections 2.1. and 2.2.) about barriers to eco-innovation along the innovation cycle and possible policy responses functioned here as an initial analytical lens to interpret the empirical findings revealed in an iterative process between theory and findings (Mantere, 2008; Patton, 2002). We now further detail the research context, the case selection and data gathering as well as the analytical approach.

3.2. Research context

Germany has a strong focus on innovation-led growth, public–private cooperation, comprehensive environmental regulation and a particular financial system, and plays a leading role in conducting a systematic transition towards sustainable energy systems using eco-innovations. These conditions are relevant to describe here as they have consequences for our research design, which focuses on innovation intermediaries' finance mobilisation functions. First, the eco-innovation industry structure, consisting of large firms and small and medium-sized firms (SMEs), is orientated towards leading-edge technologies and therefore has strong ties with universities. These often take the form of PPPs, which require intermediation between public and private entities. Second, the conservative bank-based system focuses on investment banking and project finance, thus lacking an institutionalised finance system (i.e. pension funds and other institutional investors that invest in VC and private equity) as in the UK or the US. Consequently, other forms of financial intermediation are required for services usually provided by VCs in the US and the UK. Third, the strongly mission-driven government that devises proactive public policies to overcome existing lock-ins and path dependency creates a need for intermediation between innovators and policymakers.

3.3. Case selection

Policymaking for innovation is carried out by the German Federal Government and the 16 Länder governments (state governments). R&D activities are conducted by a range of SMEs and larger companies as well as a range of higher education institutions, academies and research organisations (Max-Planck Society, Fraunhofer Society, Helmholtz Association, Scientific Community Gottfried Wilhelm Leibniz). Intermediaries between these three parties include the German research association (DFG), public and private project-managing organisations as well as industry associations and chambers of commerce. Rather than designing a statistically representative sample, we wanted to select cases that are valuable to investigate in light of our research question (Siggelkow, 2007), and thus we applied purposive sampling (Eisenhardt, 1989; Yin, 2009). Hence, we focus on project-managing organisations, as they occupy a critical innovation intermediary position within a broader eco-innovation project context consisting of several organisations, influencing the exchange of different types of resources important to eco-innovation (see Fig. 1). These public or private corporations gain their mandates from ministries in a competitive process. On the basis of their mandate obtained from the ministry, they can be considered institutional innovation intermediaries that play a critical role in bringing public and private actors together.

Our sample includes six project-managing organisations that manage most of Germany's cooperative R&D projects. They are not solely dedicated to stimulating eco-innovations; however, to study their role in this specific context, we focus on 20 government-supported eco-innovation R&D partnerships at different stages in the innovation cycle (Table 2) managed by these organisations. These projects appertain to the German Research for Sustainable Development framework (in 2007 started as High-Tech Strategy on Climate Protection) that aims at fostering eco-innovation with a technical focus on energy production and efficiency, mobility and materials, among other things. Fig. 1 depicts an overview of the research setting.

For our study, we contacted leading individuals from all project-managing organisations executing the abovementioned 20 R&D partnerships. The surveyed project managers possess broad knowledge about the ongoing research process and are aware of the regulatory environment. They are also able to establish links between financiers and supported organisations, as they manage relationships consisting of

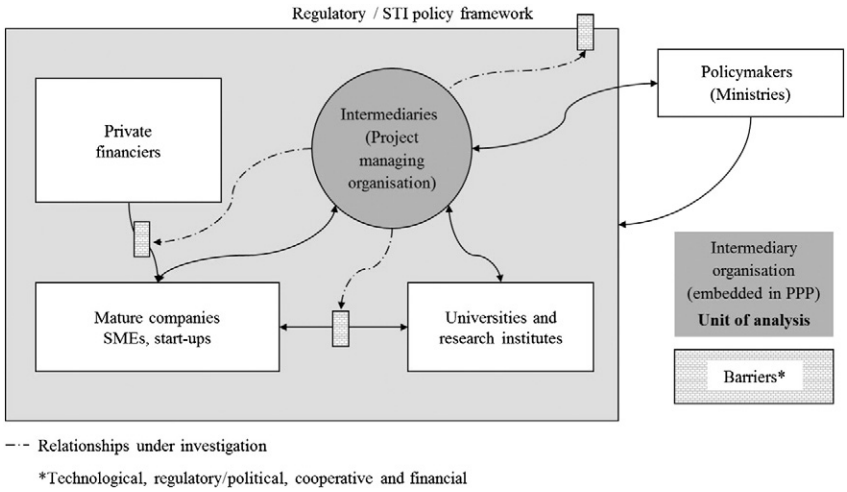

Fig. 1. Position of the intermediaries within the research setting.

flows of information and finance within R&D projects (Fig. 1). An overview of the organisations and individual interview participants can be found in Table 3.

3.4. Data collection and analysis

In case study methodology, data collection means reconstructing a phenomenon or a case by means of archival data, interviews or other artefacts and gaining understanding based on an analytical lens at the same time (Flyvbjerg, 2006; Yin, 2009). The overall investigation took place from January 2012 to March 2013 and consisted of a review of relevant documents to familiarise ourselves with the research context and of in-depth interviews and a validating workshop to analyse innovation intermediaries' functions, in particular those relating to mobilisation of finance. Using different data sources also allowed for triangulation of data to enhance internal validity (Moran-Ellis et al., 2006). First, we reviewed industry reports and reports on climate and innovation policy, and we specifically analysed the Research for Sustainable Development framework for recent and ongoing R&D partnerships. These documents (e.g. roadmaps, technology documentation, ministerial and participant descriptions) provided basic information about actors, technologies and the innovation process and helped us develop an understanding of how R&D partnerships are structured and the kinds of barriers faced. We distinguished these partnerships in a continuum from early stage (R&D) to later stage (diffusion), as the various phases typically require different financial instruments and face different barriers (see Table 1). In addition, the financial requirements (€2.5 m–€600 m) and the ministries responsible for the partnerships (see

Table 3
R&D partnerships and interviewees.

R&D partnership	Project-managing organisation(s)	Ministries	Interviewees
E-Mobility	VDI/VDE Innovation + Technik GmbH	BMBF, BMWi, BMVBS	2 research project managers
Bioeconomy	Forschungszentrum Jülich GmbH (PTJ)	BMELV, BMU, BMBF	Head of research
Biofuels	Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMELV	1 research project manager
Fuel cells	Forschungszentrum Jülich GmbH (PTJ) NOW GmbH	BMBF, BMWi, BMVBS BMU	2 research project managers
Carbon capture and storage	Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMWi	2 research project managers
Carbon nano tubes	Forschungszentrum Jülich GmbH (PTJ)	BMBF	1 research project manager
CO_2 sequestration	Forschungszentrum Jülich GmbH (PTJ)	BMWi, BMBF, BMVBS	1 research project manager
Chemical usage of CO_2	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	BMBF, BMU	2 research project managers
E-Energy	Deutsches Zentrum für Luft- und Raumfahrt (DLR) Forschungszentrum Jülich GmbH (PTJ)	BMWi, BMU, BMVBS	2 research project managers
Geo-information	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	BMBF	2 research project managers
Geothermal energy	Forschungszentrum Jülich GmbH (PTJ)	BMU, BMBF	1 research project manager
Green Carbody Technologies	Projektträger Forschungszentrum Karlsruhe (PTKA)	BMBF	1 research project manager
Advanced materials	Forschungszentrum Jülich GmbH (PTJ)	BMBF	1 research project manager
Light emitting diodes (LED)	VDI Technologiezentrum GmbH Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMWi, BMU	2 research project managers
Lithium ion battery	Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMWi, BMVBS, BMU	1 research project manager
Organic light emitting diodes (OLED)	Forschungszentrum Jülich GmbH (PTJ) VDI Technologiezentrum GmbH	BMBF	2 research project managers
Organic photovoltaics	VDI Technologiezentrum GmbH Forschungszentrum Jülich GmbH (PTJ)	BMBF	2 research project managers
Photovoltaics	Forschungszentrum Jülich GmbH (PTJ) VDI Technologiezentrum GmbH	BMBF, BMU	2 research project managers
Next Generation Solar Energy	Forschungszentrum Jülich GmbH (PTJ)	BMBF	1 research project manager
Intelligent mobility	TUV Rheinland	BMWi, BMVBS, BMBF	1 research project manager

Notes: underlining indicates leading ministry. BMBF: Bundesministerium für Bildung und Forschung (Federal Ministry for Education and Research); BMWi: Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy); BMVBS: Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry for Traffic, Construction and Urban Development); BMELV: Bundesministerium für Ernährung, Landwirtschaft und Forsten (Federal Ministry for Food, Agriculture and Forestry); BMU: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Protection and Reactor Safety).

Table 3) as well as the participating actors (SMEs, MNEs, start-ups, universities, research organisations) differed widely. These descriptions were used in interviews. As a second step, the interviews enabled us to acquire an in-depth understanding of the peculiarities of specific cases. The number of interviewees per unit varied between one and two depending on the organisational setup of the R&D partnership, with a total of 25 interviews (see Table 3). We conducted the interviews in sequential order to enable the transfer of insights from each case to an improved interview guide for subsequent cases. Each interview took between one and two hours and was conducted face-to-face or via telephone, with one or two researchers present. The interviews were tape-recorded with the interviewees' approval and transcribed verbatim to ensure correct interpretation. All interviews followed a semi-structured outline, with a set of guiding questions repeated at each interview (see Appendix A.1 for the interview guide). Thirdly, the aggregated findings were discussed, validated and extended during a workshop consisting of 15 study participants and five additional R&D project managers in similar positions. The workshop process was also recorded and transcribed.

To infer patterns from the collected data, we employed axial open coding with emerging categories (Dougherty, 2002), guided by an overarching theoretical understanding (Patton, 2002). We used the software MaxQDA 11 for the text analysis and to manage the data. Our initial findings were validated through the workshop on the barriers to eco-innovation, as the workshop participants focused on the financing problems for (eco-)innovations and intermediaries' role therein.

4. Findings

Using the data from our analysis, we first describe the identified financial barriers to (eco-)innovation that are linked to other forms of barriers typically addressed by innovation intermediaries, such as technological, regulatory, cooperative and knowledge or information barriers. We then analyse the role of institutional innovation intermediaries in addressing these barriers, focusing on their finance mobilisation functions. Finally, we analyse how, on the basis of their role and their use of these functions, intermediaries exert an influence on the innovation process of selected technologies. Representative quotes can be found in Appendix A.2. The two examples highlighted in Box 1 and Box 2 provide an in-depth understanding of the most advanced intermediary role and the possibilities to address (financial) barriers involved in the respective projects.

4.1. Intermediaries' perspective on the relation between financial and other barriers to (eco-)innovation

Our document analysis revealed indicative financing needs for each of the R&D partnerships and corresponding innovation cycles; however, the documents seldom addressed financial aspects in the context of technology and industry development. The interviewees also kept returning to the perceived barriers to eco-innovation along the innovation cycle as a major theme. From an intermediary position, this perspective provides valuable insights. The analysis of the interviews, however, revealed that financial barriers often pertain to other aspects such as the political environment and corresponding barriers, technological barriers, commercialisation, information asymmetries, intermediaries' competences and limitations, and public–private cooperation, depending on the phase in the innovation cycle.

In the basic research phase, the R&D project managers highlighted technological barriers such as complexity and administrative barriers such as criteria for the selection of projects. These translated directly into constrains regarding funding (i.e. grants), as well as other potential sources of finance for further development. Once the applied R&D phase was entered, the experts stressed the lack of orientation towards commercialisation, both on the private side – such as slow adoption of technologies, a lack of cooperation along the value chain, low corporate R&D – and on the public side, i.e. limited ability to make the technological development process transparent, a lack of links between STI and industrial policy and of public–private interaction (commercial viability or business models for technologies). These barriers relate to a lack of private risk capital (i.e. business angels or VCs) and uncertainty about further public funding for the technologies under development.

Throughout the demonstration and pre-commercial phases the R&D project managers referred to severe financial barriers on the private side, e.g. capital intensity and a lack of collateral, bankability, insurability, competence problems and too short time horizons for financiers. On the public side, administrative barriers were highlighted, such as a lack of interfaces between phases in the innovation cycle and government bodies and limited opportunities for the intermediaries themselves to address this gap. Finally, institutional barriers such as infrastructure were mentioned.

For the niche-market, the supported commercial and the fully commercial phases, the interviewees perceived a high path dependency on the private side regarding technologies and business models but also high regulatory and political uncertainty and inconsistent support for different technologies (i.e. picking the winner problem) on the public side. Public–private barriers arise from commercialisation efforts being made too early as a result of technology push measures and responding private actors, as well as infrastructure problems. In addition, there is a lack of compatibility between private finance and public support initiatives.

To summarise, from the perspective of institutional innovation intermediaries, these findings indicate that technological, cooperative and political barriers along the innovation cycle translate into financial barriers (see Section 2.1.). This translation takes different forms along the innovation cycle. In the early stages, technological and administrative barriers such as an opaque technology development process and uncertainty about the technological and commercial prospects limit the matching with funding sources and thus result in early stage financial constraints. A lack of orientation towards commercialisation including a focus on costs and potential business models and a lack of interfaces between ministries and stages in the innovation cycle, combined with financiers' limited capabilities to evaluate commercial viability, translate into a severe gap for private risk capital during the demonstration and niche-market phases. During the later stages of the innovation cycle (supported commercial and fully commercial), regulatory and policy uncertainty as well as inconsistent support mechanisms translate into large investment projects and infrastructure being delayed or withdrawn, and this conveys a significant financial barrier.

4.2. Role of institutional innovation intermediaries in addressing these barriers

Having outlined the perceived technological, cooperative, regulatory or political and corresponding financial barriers, we analysed the role of institutional innovation intermediaries in addressing these barriers and correspondingly mobilising the private finance inhibited by the different barriers.

4.2.1. Competences and mandates regarding commercialisation

Although the intermediaries institutionally are equally positioned in the innovation system (see Fig. 1), we found a variety of roles, competences and mandates that impact their functioning within their respective contexts. The surveyed project managers see themselves as experts – a prerequisite for fulfilling the managerial task of the R&D partnerships. Secondly, they act as bridge-builders between critical actors in the innovation system – within the supported R&D projects and the corresponding participants – that address cooperation barriers in the early stages. However, only few explicitly regard themselves as competence centers designed to bridge the gap between R&D and commercialisation and address underlying financial, regulatory and technological barriers.

The R&D project managers allocate resources between projects, channelling public funds, selecting participants, and documenting and

controlling the process as well as the usage of the generated knowledge (products, processes or patents). Some of them do not see a relevant role for themselves within that process, whereas others have a holistic understanding of their managerial capabilities. Most surveyed project managers have a broader commercial understanding, and this is supported by the analysis of archival documents for each field. However, only a few directly address barriers such as capital intensity and scalability on the private side and the lack of infrastructure on the public side. The LED lighting initiative in Box 1 is one of the few examples.

Box 1
LED lighting R&D and lead-market initiative.

The LED has been government supported since its potential for general lighting was discovered at the end of the 1990s. The project-management organisation and individual project managers financed *basic and applied research* pushing the technology from small-scale to large-scale application along the technological life cycle, with a focus on interfaces between ministries and stages. The aim was to provide the German lighting manufacturers with the possibility to cope with the transition towards solid state lighting (i.e. LED). Thus mostly *mature companies*, *research institutes and universities* benefited from this programme. On the brink of commercialisation in 2009, the ministry together with the project-managing organisation launched the LED lead-market initiative, which aimed at accelerating LED commercialisation and diffusion. This initiative was an *institutionalised public–private cooperation* coordinated by the project-managing organisation. Here, the project managers acted as *bridge-builders and innovation managers with a clear commercialisation perspective*. Main topics included the financial and organisational barriers to innovation such as risk and uncertainty regarding business models based on LED. These barriers were evaluated against the current institutional and regulatory environment. Thus, feedback to design conducive regulations was provided by the project-managing organisation. Throughout the lead-market programme, *demonstration projects*, *application programmes and public–private instruments* (e.g. standard energy service contracts for lighting application) were developed. Further results included *guidelines for LED modernisation and certificates* to ensure quality.

4.2.2. Supporting policymakers to influence the finance environment

Because of their contractual relationship with government ministries and the resulting innovation agent characteristic of the institutional innovation intermediaries, a major role revolves around institutionalised dialogue with political actors. In this respect, intermediaries act as consultants influencing the design of R&D programmes. Because of their critical position between policymakers and industry, the surveyed managers also engaged deeply with the review and extension of existing regulations. Most study participants established the link between the policy environment and their technology field, a few with consequences for advanced eco-systems, especially the finance environment. However, they still regard their influence on the accompanying regulatory environment as limited, especially in the niche-market and supported commercial phases.

Within our narrative analysis, the interfaces between different stages of the innovation cycle that leave structural holes such as 'the valley of death', the actors responsible for the situation and the appropriate instruments to correct these failures cropped up as major themes. This includes the responsibilities of different ministries along the innovation cycle as well as the coordination of support mechanisms. Most of the intermediaries address the structural holes in the innovation process, notably the transition from basic R&D to applied R&D and 'the valley of death', on the brink of commercialisation. Nonetheless, several R&D managers did not see the transition towards commercialisation as their responsibility, or even considered this would put their independent position as brokers between public and private actors at risk as they saw this as placing themselves too much into the position of the innovation firms. Although their mandate from the ministries entitles them to create synergies and foster innovation, providing too much support for market creation seemed beyond their scope for some of them as they felt they would alienate themselves from public sector organisations.

4.2.3. Financial instruments and cooperation with financiers

The R&D project managers possess a set of instruments to support the innovation process to address the abovementioned barriers. They include various subsidy schemes, socio-economic research and start-up support schemes, as well as instruments targeting the later stages of the innovation process, e.g. commercialisation, which requires contacts with public or commercial funds. These contacts might take various forms and are seen as a new competence for R&D project managers. Additionally, supporting tools such as roadmaps were highlighted. These tools make the technology development process (including complementary assets such as infrastructure) understandable to third parties and help in coordinating actors.

Other interviewees argue in favour of integrating VC as an instrument for effective support of SMEs and start-ups, to signal quality towards potential financiers. There is often a deficit of external capital, as shown in the example in Box 2 of the smart-grids innovation programme (E-Energy). However, information used as a signal for potential financiers or other private actors might be confidential or unavailable in aggregated form. Supplying these data could mean a conflict of interest for the intermediaries. Nonetheless, R&D project managers could provide complementary research to reduce the risks to private financiers.

In sum, two possibilities to address financial barriers emerged. The intermediaries could either directly use their instruments to address financial barriers, especially relevant in the case of SMEs, or they could shape the policy environment to address regulatory risks and uncertainty in the later stages in order to provide incentives for larger companies to invest in innovation.

During the workshop, the participants highlighted their finance mobilisation functions to address specific structural gaps and financing needs. Two solutions emerged: first, the integration of a market perspective in the design of R&D programmes to permit a smooth transition between R&D and commercialisation; second, the use of bridge-building and gatekeeping functions later in the innovation process to provide interfaces between the market participants.

Box 2
Smart-grids Innovation Programme (E-Energy).

The smart-grids innovation programme aimed to demonstrate the feasibility of using existing and novel eco-innovations in intelligent model regions. Thus, the initiative focused explicitly at the *outset on applied R&D and commercialisation*. It specifically addressed *SME and start-ups*, which have been particularly active in this clean-tech subsector. The project-managing organisation took an *innovation management approach*, focusing on problems that SME highlighted as barriers to accelerated commercialisation: the lack of business models and the limited access to VC for a quick scale up. They consequently applied instruments such as *prizes for founders and a holistic model region approach*. The combination of *VC and R&D grants* as financial instruments has not yet been implemented, although the responsible project manager framed it as a possibility to address financial barriers. *Standardisation* as a technological barrier was further referred back to the corresponding ministries to be addressed on a regulatory level.

5. Discussion

The research question guiding our enquiry was: *How do institutional innovation intermediaries address the complex set of barriers surrounding (eco-)innovation especially from R&D to commercialisation, with an emphasis on mobilisation of finance*? In this section, we reflect upon this research question and interrogate our findings with previous insights from the literature on innovation finance and on innovation intermediation in order to show the specific role of intermediaries in mobilising finance and how this relates to addressing barriers to eco-innovation.

5.1. Addressing financial barriers requires a holistic perspective on the interrelatedness of different kinds of barriers

Due to high public–private uncertainty, R&D complexity and learning in the early stages, (eco-)innovations need increased support, coordination of activities and the development of complementary assets (e.g. infrastructure, standards and so forth) (Kenney and Hargadon, 2012; Haley and Schuler, 2011; Mathews et al., 2010). Thus, especially in the case of eco-innovation, systemic innovation support efforts are needed to escape lock-in effects and path dependency and to accelerate the commercialisation and diffusion of eco-innovations by balancing regulation, innovation and complementary financial mechanisms (Hekkert and Negro, 2009; Moore et al., 2012b; Perez, 2013; Hargadon, 2010).

Hence, financing eco-innovation requires a holistic perspective on the innovation cycle including the commercialisation and diffusion stages, as well as the transition between the phases and possible barriers connected to each phase, as shown by our analysis from the perspective of institutional innovation intermediaries. Each phase requires different forms of financing and support to address the underlying financial and non-financial barriers along this cycle. For example, major barriers to the successful commercialisation of fuel-cell cars revolve around infrastructural barriers. By bringing together partners from the automobile and gas industry and assisting in developing technologies and business models for infrastructure, the intermediaries could address major technological and institutional barriers that ultimately translate into financial barriers and prevent commercialisation. According to our findings, institutional innovation intermediaries thus possess, or can make linkages to, the instruments that address the underlying financial aspects relating to barriers along the innovation cycle, such as capital intensity, scalability, infrastructure, lock-ins, regulatory risk and policy coordination failures. In the next section, we discuss the key strategies deployed by institutional innovation intermediaries that emerged from our findings.

5.2. Unravelling direct and indirect finance mobilisation functions of institutional innovation intermediaries

From our analysis of intermediary roles and instruments, we derive a set of functions that permit institutional innovation intermediaries to influence the finance environment for (clean) technologies and consequently accelerate the commercialisation and diffusion process. Finance mobilisation functions comprise not only strictly financial instruments but also instruments that indirectly influence the finance environment for eco-innovation.

Firstly, classical innovation intermediation functions, such as matchmaking to establish R&D partnerships, adding and removing participants, knowledge brokering to ensure knowledge exchange in R&D partnerships, contract and conflict management, patent brokering and consulting (Howells, 2006; Yusuf, 2008), indirectly impact the finance environment. Intermediaries are able to accelerate the commercialisation process by establishing and managing strategic R&D partnerships and by making connections to supportive innovation policy instruments such as roadmaps, strategic public procurement or production support measures, thereby making the technology innovation process more transparent. This contributes to the reduction of uncertainty about future market opportunities (Hoppe and Ozdenoren, 2005). On the basis of these findings, we argue that these instruments used or operationalised by intermediaries influence the quality of the R&D partnership and increase commercial viability, which in turn influences the attractiveness for private financiers to invest in companies and complementary assets.

Secondly, the findings highlight intermediaries' indirect finance mobilisation functions, in that they influence STI policy and regulation surrounding the technologies under development through their advocacy activities, as has already been observed elsewhere (Kivimaa, 2014; Klerkx and Leeuwis, 2009; van Lente et al., 2003). In addition to the beneficial effects of adequate STI policy and regulation for innovation and commercialisation, this indicates that support for favourable STI policy mechanisms and regulation directly determines the ability of private investors to invest in young, small and more mature companies. These investments are especially relevant in the context of eco-innovation as these technologies exhibit a strong regulatory dependency and asset heaviness.

The third component of more direct finance mobilisation functions revolves around the cooperation with private financiers to improve their competences regarding innovative (clean) technologies and thus strengthen their ability to evaluate future market opportunities. Reduction of information asymmetries has been highlighted in the context of markets for technologies (between producers and users) (Hoppe and Ozdenoren, 2005; Boon et al., 2011); through our analysis, we found that it is especially relevant in the context of financing (eco-)innovation since the information asymmetries between financiers and innovators are greater in this area than in others.

Fourth, direct financial instruments represent probably the most obvious part of direct finance mobilisation functions to alleviate financial constraints for innovating firms and research institutes. These include subsidies, grants, tax credits and support for demonstration projects (Borrás and Edquist, 2013; Meuleman and De Maeseneire, 2012; Brown and Hendry, 2009). Our analysis adds to this earlier work by indicating that it is critical to use an adequate and appropriate financial mechanism (public, private or PPP – based on the risk/return profile) to allow a seamless transition between the phases of the innovation cycle. This includes a combination of public (e.g. grants) and private (e.g. VC) instruments in later stages to leverage the publicly invested money.

5.3. The synergic combination of direct and indirect finance mobilisation functions of innovation intermediaries

As discussed in Sections 5.1 and 5.2, we argue that, in order to address the interwoven barriers highlighted above, innovation intermediaries need to apply different roles and corresponding instruments for each stage of the innovation cycle. We highlight the fact that finance mobilisation functions are critical to support and accelerate the innovation process for eco-innovations by intermediating between public policymakers, private financiers and innovators. From our findings, we derived the model depicted in Fig. 2.

The different direct and indirect finance mobilisation functions are synergic, as becomes clear from the findings in different ways. First, and this could be called a first-order effect, intermediaries capitalise on the strength of public–private cooperation (i.e. innovation intermediation – acting as expert, bridge-builder, innovation manager), focusing on bottlenecks along the innovation process to bridge the 'valley of death' and other structural holes, thereby going beyond funding basic or applied R&D and demonstration. Howells (2006) described this as a generic role throughout the commercialisation phase. In the early stages, institutional innovation intermediaries coordinate different sources of capital (e.g. research grants, PPP, private sources of capital) that represent the direct financial instruments component of our

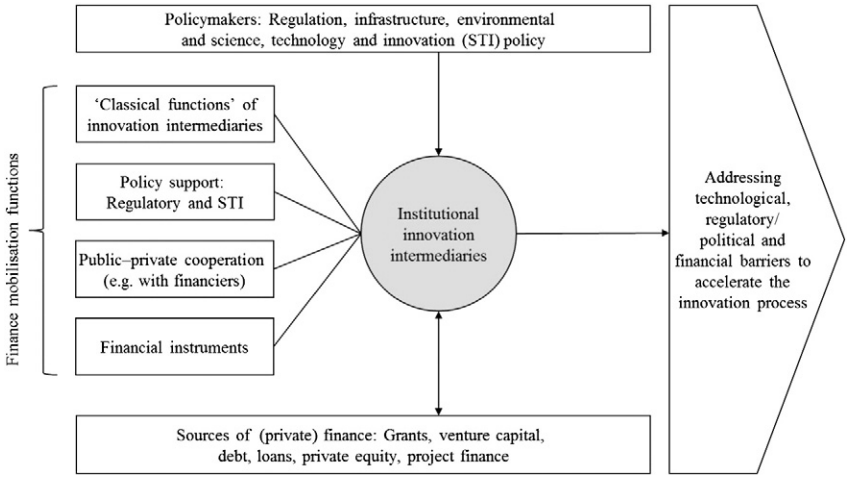

Fig. 2. Model for intermediaries to address barriers to (eco-)innovation.

concept. The focus on bottlenecks additionally addresses barriers such as policy coordination and reflexivity failures, highlighted by Weber and Rohracher (2012).

Second, as a second-order effect, they accelerate the innovation process by supporting the design of a policy environment that is conducive to the innovation process, spanning from complementary assets towards regulation to indirectly change the finance environment. This finding supports work that argues that, as a whole, finance mobilisation functions could act as a lever for publicly invested money and permit the thickening-up of thin finance markets for (eco-)innovations (Kleer, 2010; Nightingale et al., 2009; Meuleman and De Maeseneire, 2012). Our findings reveal that a technology-specific assessment of policies is necessary to facilitate financing (eco-)innovation. The development of complementary assets (e.g. infrastructure, standards) or research to reduce risks enable private financiers to more seamlessly invest in the commercialisation phase of (clean) technologies and thereby overcome corresponding barriers.

Thirdly, there is a synergy between public and private actors in the sphere of innovation finance, as institutional innovation intermediaries act in a translating, moderating and mediating way between market and non-market actors to support market creation. This form of intermediary complements informed investors (which to some extent may also be considered intermediaries) such as VCs (Leete et al., 2013; Da Rin et al., 2006; Repullo and Suarez, 2000), as they are capable of reducing uncertainty and risk. Financiers (such as VCs and banks) are not able to grasp the complexity of the whole innovation process, especially in the case of system innovations such as many eco-innovations, or only perform certain types of investments such as complementary assets (e.g. infrastructure), especially for eco-innovations. Hence, here the link between VC and institutional innovation intermediaries takes the form of what Stewart and Hyysalo (2008) have dubbed an 'ecology of intermediaries'.

5.4. Limitations of the study

Since intermediation is a context-dependent phenomenon, we acknowledge limitations to our study. The study's qualitative nature prevents us from generalising our findings. Nonetheless, the surveyed partnerships represent typical cases for high technology research. Thus, the model based on our findings could be transferred to other forms of organisations or government agencies in other contexts, as the functions remain universal. Organisations that have similar responsibilities and face similar barriers exist in other countries. They include the Department of Energy National Laboratories in the US, the Finnish Funding Agency for Technology and Innovation (TEKES) or the Department of Trade and Industry (DTI) in the UK. However, depending on the degree of influence from institutional conditions, i.e. structural R&D support in the national innovation system, the transferability of our findings may be limited. To gain a deeper understanding of the interaction between institutional intermediaries, innovators and financiers, additional studies need to be conducted in other highly uncertain fields of technology.

6. Conclusion and policy implications

In this study, we show that institutional innovation intermediaries with both their direct and their indirect finance mobilisation functions accelerate the commercialisation and diffusion of (eco-)innovation. Our findings complement earlier work that has been looking at single public and private instruments to finance innovation (Auerswald and Branscomb, 2003), notably research programmes and grants (SBIR/-ATP) (Link and Scott, 2010; Chang et al., 2002) and VC or business angels (Leete et al., 2013; Kenney and Hargadon, 2012; Nightingale et al., 2009). Our research confirms the utility of individual funding instruments; however, we highlight restrictions of these instruments with regard to their coordination and embeddedness within the overall innovation system and process in order to thicken up the thin financial markets for eco-innovation. This requires a focus on the interfaces between the innovation process stages and their connection with the policy environment. So, coordination of the variety of innovation-financing policy instruments available to institutional innovation intermediaries addresses the void of finance mobilisation functions that results in many technologies failing to transit from research to market (Jacobsson and Karltorp, 2013; Mathews et al., 2010; Bergek et al., 2008).

Our findings hence provide empirical support for the argument put forward by Wonglimpiyarat (2011), who found that the financial innovation system underlying national and technological innovation systems is a significant driver of innovation activity. We show that financial barriers interact with technological as well as regulatory barriers along the innovation cycle, and that here institutional innovation intermediaries can play an important role in strengthening and connecting the financial innovation system with other actors and institutional arrangements (i.e. policies, support instruments) in the innovation system.

Two important policy implications can be derived from our study. First of all, policymakers should consider financial barriers and related technological, cooperative, and regulatory or political barriers as intertwined. By ignoring the linkages between financial and other

barriers, i.e. by considering innovation and finance separately, policymakers lose the potential to support critical industries such as clean-tech in an efficient and effective way. Second, institutional innovation intermediaries with specific finance mobilisation functions represent a crucial instrument for policymakers to operationalise and enhance eco-innovation. Policymakers should therefore extend the mandate of institutional innovation intermediaries beyond the (technical) applied research phase towards commercialisation and diffusion (including a focus on policy environment and consequences for finance), as many barriers occur at the beginning or in the transition between phases. They could capitalise on the intermediaries' position in the innovation system to facilitate exchange between financiers and innovators at an early stage, to optimally coordinate public support for the development of technologies along the innovation cycle and correspondingly support market development.

Acknowledgements

The authors are grateful for the time and support of the interviewees and workshop participants as well as Horst Steg (DLR). Valuable comments on earlier versions of the paper were provided by Florian Täube and Christian Friebe (Sustainable Business Institute), Paul Nightingale (SPRU — University of Sussex) and Paula Kivimaa (Finnish Environment Institute SYKE), three anonymous conference reviewers and two anonymous journal reviewers. The opportunity to present and discuss earlier versions of the paper at the Oikos Young Scholars Entrepreneurship Academy 2012, DRUID Summer Conference 2013 and the Academy of Management Conference 2013 helped us tremendously in further refining our argument. The research team would like to thank the Federal Ministry of Education and Research (BMBF), Germany, for their financial support as part of the research project Climate Change, Financial Markets and Innovation (CFI), 2008-2013 [grant number 01XX0801A].

Appendix A

A.1. Interview guide.

General questions concerning R&D partnership
- What is the main focus of R&D partnership (R&D, commercialisation, diffusion)?
- How did the technology evolve?
- Who are the directly and indirectly participating actors (i.e. firms, research institutes, etc.)?
- What are goals of the project-managing organisation and participants (industrial, academic)?
- How long has the R&D partnership lasted?
- Please describe the commitment of the participants (monetary and non-monetary).

Management R&D partnership
- Please describe your role regarding tasks, responsibilities, expertise, hierarchy, status and coordination.
- How are participants selected and resources allocated?
- What kind of criteria did you apply to select the participants (expertise, commercialisation, competences, work plan, risks, leverage effect, overall importance, financial power)?
- Please describe the evaluation of R&D projects, especially regarding transparency.
- Please describe your internal and external communication strategy.

Science, technology and innovation (STI) policy
- Which ministries are responsible for this R&D partnership?
- What are their goals?
- What kind of policy measures (e.g. lead markets) do they use?
- Please describe your influence on STI policy.
- Please describe the barriers to commercialisation and diffusion of technology X.
- Which policy instruments could reduce those barriers?

Cooperation
- Please describe the private–private cooperation (actors, forms, barriers).
- Please describe the public–private cooperation (actors, forms, barriers).
- Please describe the public–public cooperation (actors, forms, barriers).

Financing
- Do you think finance is necessary for commercialisation?
- Do you discuss questions relating to finance with industrial partners?
- What kind of follow-up finance do they need?
- Have participating actors successfully been (externally) financed?
- Have projects or companies been discontinued due to lack of finance?
- Start-up and growth finance (Business angels, VC, PE; Mezzanine, Banks)
  - Which questions are addressed? Who deals with them?
  - Is there a need for start-up and growth finance? Who are the contacts for the participating actors?
- Please describe your cooperation with financiers.

A.2. Supplementary data (i.e. organised quotes)

Representative quotes.

Antecedent	Characteristic	Representative quotes
Barriers to eco-innovation	Technological	The production technology area is complex. Tasks are complex, equipment is complex and finally we need partners who buy the products, meaning reliable partnerships (Research project manager, Carbody technologies). I see a deficit in the 'Mittelstand'. How do we make those companies more innovative? (Head of research, Biotechnology).
	Regulatory/political	Recently we have been overwhelmed with bureaucracy. Nowadays we need to document why we support mature companies (Research project manager, Advanced materials). We are limited by rules for granting support, public procurement law, etc. We are not allowed to support individual firms but we can take measures that enhance innovation in Germany as a location for businesses (Research project manager, Smart grids). Infrastructure is a technical and a cost challenge. We have access to comprehensive analyses (Research project manager, Fuel cells). Regarding the vehicles [the main barriers] are costs. In terms of technology, we rather see an optimisation problem which is the case for all new technologies. [Fuel-cell cars] are disadvantaged compared to incumbent technologies. The incumbent technologies respond to user demands but ignore other challenges (Research project manager, Fuel cells). Only political barriers remain for CCS, especially acceptance among the population. Nobody would initiate a demonstration project if it was not safe (Research project manager, Carbon capture and storage). The cost target is not yet achieved. The question is, what to do in-between [R&D and commercialisation]. Financial incentives to account for the higher upfront investment are desired by industry. […] However a feed-in tariff as for the renewables would not be adequate (Research project manager, Fuel cells).
	Cooperative	In that case we have to assure confidentiality, especially towards our project partners. We know interesting numbers. […] The goal is to move beyond R&D (Research project manager, Photovoltaics). As you can imagine, this information [market developments, expertise, evaluations of technologies] is confidential. We only report aggregated data. But the companies also have limitations in terms of what they can share (Research project manager, Carbon capture and usage technologies). Financiers have built up competences since the 1990s, especially in banks and venture capitalists. However, we are not asked for advice (Head of research, Biotechnology).
	Financial	We had good projects which we could not fund due to insufficient budgets. The industry is not willing to invest. That is critical. […] We hear this a lot from our project partners (Research project manager, Solar energy technologies). We need to find someone who is willing to invest and bear the risk. We need to find someone who is willing to do that in Germany. I do not think that taxpayers will be excited if we fund a German company which establishes its production facility in Asia, the US or elsewhere (Research project manager, Battery technologies). The feedback from our demonstration projects, where smart homes are deployed, is that there is only a business case when the pay scale fits the user needs (Research project manager, Smart grids). R&D is important, but we have realised that, apart from supporting technology policy, industrial policy monitoring is necessary. […] What kind of instruments could we use? Loans for market introduction? After the R&D phase, technologies need 5–10 times more investment for commercialisation. Can companies bear this burden? Do they get private finance or not? (Research project manager, Smart grids). The problem is credit-worthiness [for co-financed R&D projects and for commercialisation efforts]. It is a real financing problem. When they apply for an R&D project, they need collateral. Sometimes banks give guarantees, but this is rare. There I see the main problem for our companies (Research project manager, Smart grids). [The company] has left the R&D phase early. At some point in time, they did not have enough financial resources. They built a production facility early without actually knowing what they are producing. So the costs where high and the market did not take the products (Research project manager, Organic LED). Currently, [potential buyers of the innovative technology] rather go with the subsidies instead of private energy service contracting. If we do not subsidise the products anymore, contracting will be used (Research project manager, LED).
Roles, competences and mandates	Expertise	It is not the case that we could go into the laboratory ourselves and take over the work there, but we know the main research streams and their contents very well. We need to know where the problems are and what the solutions could look like (Research project manager, Organic LED).
	Knowledge broker	We see ourselves as brokers. We work for the ministries but somehow also for the industry. That means we attempt to bring together different points of view. That is our strength because we are familiar with different sectors. We are in the best sense mediators, and we try to advance the opinions of others rather than our own (Research project manager, Photovoltaics).
	Technology transfer	We funded these technology centres for 10 years. There is a lot of know-how, numerous highly ranked publications and eminently respectable researchers, […] but what we originally intended, the next step, technology transfer into the firms [did not happen], the firms acted very conservatively (Head of research, Biotechnology programme). That is the mission of most funding programmes, it is about technology transfer. On one hand, we have industrial R&D which is done autonomously. On the other, we have university R&D, Max-Planck-Society — basic research. The Government tries to close the gap by using project funding and by supporting technology transfer (Head of research, Biotechnology).
	Bridge-builder	It is our task to make sure that everyone gets a word in edgewise, to ask critical questions and to determine what is important. In general, representatives from the corresponding ministry are present. […] It makes sense that they concentrate on content. So in the end it is our duty to collect information, to channel it and to question what is really needed (Research project manager, Organic photovoltaics).
	Manager	I think we do not need to do cost-revenue-control; the firms are doing that already. And we get ambiguous feedback. There are companies saying that it is helpful what you do and others do not feel informed enough (Research project manager, LED). We evaluate [projects] according to a matrix, e.g. market perspective 40%, congruency with national fuel-cell initiative and sustainability. It is not about proof-of-concept; we want to prepare the market […] in the field of transport and infrastructure (Research project manager, Fuel cells).
	Influence on STI policy	It is not that we dictate something […]. We rather make our point and summarise things, which is already an interpretation. But we also get to know political aspects that we are obliged to include in our evaluation. […] We cannot influence it uni-directionally; we rather help them build their opinion (Research project manager, Geothermal energy). It is our task to set the stage. We would like to have this technology field and not the other. […] We need visionary

Appendix A (*continued*)

Antecedent	Characteristic	Representative quotes
		systems – what can they look like? […] We sketch what cooperative research projects could look like and what kind of actors should participate and how close to the application phase they should be (Research project manager, Advanced materials).
		Many projects produced meaningful results, but there were no business models. The regulatory framework does not permit the incorporation of the results into business models (Research project manager, Smart grids).
		[The regulation] is coordinated here, that is a huge advantage. The standardisation took place including discussions where the counter would be installed – at the car or at the motoring pump. That will be a crucial advantage in the future (Research project manager, Fuel cells).
		It's about acceptance, not only the tank vs. plate discussion, also whether the introduction of renewable resources and fuels […], could create disadvantages regarding ecology or quality of life (Research project manager, Biofuels).
		[The regulatory environment] exerts positive and negative influence on innovation behaviour. Sure, companies follow trends if they are clearly visible. Production research and the production industry are conservative as the processes are highly complex […] (Research project manager, Carboy technologies).
	Interfaces between public authorities	A concrete example was the coordination between ministry X and ministry Y. In the first place, the competences are marked off, ministry X does the research and ministry Y the application. But in the end it is a very fuzzy field (Research project manager, Lithium-ion battery).
		I think the most critical point is what happens at the end of projects concerned with basic R&D. We are not responsible anymore because we funded the basic R&D. Another ministry might still not be responsible because the application is not visible. […] You often come across the situation that the innovators do not know about the follow-up process (Research project manager, Organic photovoltaics).
	Interfaces between innovation phases	In any case, we have to answer the question: What comes afterwards? We work for ministry X and fund the research, but we do not work for the department that deals with finance and industrial policy. The transition from funded research to industrial policy is no fast-selling-item (Research project manager, Fuel cells).
		We strive for synergies and we try to reduce redundancies. But, after all, the transition from prototype or demonstration, from the R&D phase towards a mainstream product or service is a responsibility of the innovators (Research project manager, Carbody technologies).
Financial instruments	Combination of public support and private finance	There are contacts with private actors. Of course we cannot say, this is the partner bank X, Y. That cannot be our task. It is rather the question of where the [founders] turn to get their own contacts. […] We are willing to establish contacts but we cannot act as handmaidens of a bank (Research project manager, Biofuels).
		[…] I would see it as our task that, if we cannot fund them, we use our relationships with business angels who know that we have expertise in the field. However, many networks do not work, especially not between funding ministries (Research project manager, Smart grids).
		We have developed [a roadmap] with confidential company data. Especially scenarios for infrastructure, and joined these with roll-out scenarios of the automobile industry. That is different from the infrastructure for natural gas which has been conducted by the utilities that do not have an understanding of the main actors, consumers, automobile users and automobile industry. This has been done here in a coordinated way, which represents a huge advantage (Research project manager, Fuel cells).
		[Finance] is a support instrument. If creditworthiness is missing, we would have the routine […] to use venture capital or to give venture capitalists a hint about what we regard as innovative so that they become interested […]. We could also show that we expect growth in this sector over the next years or that we see a lead-market. We also show the sphere around, saying that these small companies are in a consortium with large firms. That is important information. One could also invite [private] funds for jury meetings or involve them in accompanying research. […] still this is not included in our mandate. We are limited in terms of budget (Research project manager, Smart grids).
	Limitations	You can imagine that information is partially very confidential. That means that the results we extract [from the projects] or hand on are more general. There you read medium-term commercialisation, etc. But also from the side of the innovators there are limitations on what we can hand on and what not (Research project manager, Carbon capture and usage technologies).
		We work as a contractor for a certain ministry, selling services to them, precisely giving project funding to the innovators. If we had the industry as a contractor at the same time, I would regard this conflict as critical as long as there is no organisational separation between the two processes (Research project manager, Organic photovoltaics).
	Complementary services	We supply preliminary seismic data according to model calculations, simulations; we are of the opinion that with 95% probability you will find the geologic conditions necessary for an insurer to insure the last 5% (Research project manager, Geothermal energy).

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