Research Policy 42 (2013) 647–661

Contents lists available at SciVerse ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Financing innovations in uncertain networks—Filling in roadmap gaps in the semiconductor industry

Knut Lange[a,*], Gordon Müller-Seitz[b], Jörg Sydow[b], Arnold Windeler[c]

[a] Surrey Business School, University of Surrey, Guildford, Surrey GU2 7XH, UK
[b] Management Department, School of Business & Economics, Freie Universität Berlin, Boltzmannstr. 20, 14195 Berlin, Germany
[c] Department of Sociology, Technische Universität Berlin, Fraunhoferstrasse 33-36, 10587 Berlin, Germany

ARTICLE INFO

Article history:
Received 18 May 2010
Received in revised form
22 November 2012
Accepted 11 December 2012
Available online 16 January 2013

Keywords:
Innovation networks
Uncertainty
Technological roadmaps
Finance
Semiconductor industry

ABSTRACT

Complex technologies are often developed in inter-organisational networks as actors try to reduce development costs and uncertainty about the viability of these innovations. However, as of to date it remains unclear how such innovations are financed collectively under conditions characterised by extreme uncertainty. Hence we explore how financial resources within innovation networks are mobilised and allocated. This question is of particular importance to the development of system technologies that are viable only if *all* critical components are functional on time. We explore this issue by reviewing the development of a radically new system technology for mass manufacturing microchips in the semiconductor industry. In this industry, technological roadmaps allow actors to identify critical components that still need to be developed. These components are the so-called roadmap gaps. However, suppliers can be reluctant to develop the required components at their own expense because of the high uncertainties involved. In such cases, providing financial support to component suppliers is a central task of innovation networks. The empirical analysis shows that semiconductor manufacturers take both an individual and a collective approach to filling roadmap gaps. This study contributes to prior research on innovation networks and financial management not only by identifying and clarifying these two approaches, but also by revealing under which conditions they are used. The findings are particularly relevant to scholars interested in the innovations of complex product systems (CoPS).

1. Introduction

Complex system technologies, such as transportation systems (Neven et al., 1995) and manufacturing technologies (Linden et al., 2000), are often developed in consortia or other types of inter-organisational networks. System technologies are particularly likely to be developed in such innovation networks (Freeman, 1991; Sydow et al., 2012), as organisations are confronted with high degrees of uncertainty. In line with Knight (1921), we define uncertain situations as those in which not only subjective probability estimates are unavailable to organizational actors to evaluate future outcomes, but the range of options is not even foreseeable. Thus, organisations engaged in the development of complex system technologies often collaborate in networks to not only share the calculable risks and lower the high costs (Davies, 2003), but also to deal with the fundamental uncertainties involved (Appleyard et al., 2008; Sydow et al., 2013).

In this regard, organizations do not only need to align their own R&D activities, they are also faced with uncertainty at the network- or system-level. The reason is that system technologies are only viable if *all* critical components are serviceable on time. Thus, the failure of a single critical component supplier because of a lack of competence or financial resources could lead to the breakdown of the entire development process of the system technology. As a consequence, none of the firms involved would be able to generate a return on their investments, even if they had developed a functional component on time (Chuma, 2006). Organizations involved in the development of system technologies are therefore confronted with high systemic uncertainty. This problem appears relevant not only for complex products and systems (CoPS; Hobday, 1998) such as in the aircraft, solar energy, or semiconductor manufacturing industries, but also for innovation networks like transnational scientific research centres or public-private partnership networks more generally.[1] Given this observation, it is surprising that financing innovations in

[1] Take, for instance, the large-scale basic research undertaken by the Swiss-based CERN (Conseil Européen pour la Recherche Nucléaire; Boisot et al., 2011). This research centre is in effect a large-scale innovation effort consisting of multiple organizations involved. As for a public-private partnership, consider the Diabetes Genetics Initiative of Novartis and three universities that generate insights into diabetes treatment.

* Corresponding author. Tel.: +44 1483689751; fax: +44 1483689516.
E-mail address: k.lange@surrey.ac.uk (K. Lange).

0048-7333/$ – see front matter
http://dx.doi.org/10.1016/j.respol.2012.12.001

networks–and here in particular the development of complex technological innovations–confronted by a high degree of systemic uncertainty has received hardly attention in the extant research. In prior network research, the financial dimension has not usually been considered. In the finance literature, the collective nature of financing problems is neglected. Thus, in this study, we ask the following two explorative research questions:

> How is the development of complex system technologies, usually faced with extreme uncertainties, financed in networks? Moreover, under what conditions do lead firms contribute to financing and when are more collective approaches more likely?

We answer these research questions by examining the results of a longitudinal explorative study on the quest for a radically new system technology for mass manufacturing microchips called Extreme Ultraviolet Lithography or EUVL. In the semiconductor industry, technological roadmaps allow actors to identify critical components that still need to be developed. These components are the so-called roadmap gaps. The existence of roadmap gaps creates high systemic uncertainty for the entire innovation network, especially if it is unclear which organizations are potentially able and willing to fill these gaps. We show that there are basically two ways to address this systemic uncertainty. First, collective action supported by research consortia or government-funded R&D programmes can be organised (in our case by means of collective roadmap gap financing). Second, a lead firm can emerge and absorb the systemic uncertainty by co-funding the projects of critical suppliers (in our case by means of individual roadmap gap financing).

Herein we contribute to research by theorizing financing in innovation networks under extreme uncertainty in two ways. First, we identify the mechanisms that the organisations within a network employ to finance roadmap gaps and, thereby, deal with systemic uncertainties. Second, we analyse which mechanisms are used under what conditions. Our findings are summarised in a series of propositions that provide promising avenues for future research on roadmap gap filling in particular and, at least to a limited extent, for financing the development of complex technologies in innovation networks in general.

The remainder of this paper starts with a review of the literature on networks and on financial management relevant to our research question. Subsequently, we describe our research setting, the semiconductor manufacturing industry, which allows us to analyse the financing of system technology development in great detail because of the dominance of inter-organisational networks, the high capital intensity of this industry and the extreme systemic uncertainties involved. In the method section, we introduce our explorative in-depth case study approach. In the empirical part, we first describe the systemic uncertainty that organisations face in the development of EUVL before we outline the two ways to address systemic uncertainties: collective and individual financing of roadmap gaps. Based on our findings, we discuss our results and their generalizability in the light of the literature on CoPS and develop propositions. Finally, we summarise our main contributions, discuss the limitations of our study and point to future research avenues.

2. Financing innovation in networks—a review of the literature

The management literature is silent not only about financing innovations in networks but also regarding the financial dimension of inter-organisational collaboration more generally, not considering the abundant studies of alliance and network formation on firm valuation (e.g. Oxley et al., 2009). A related body of studies that is relevant to our research question is the literature on CoPS (Hobday, 1998), as their development takes place mostly in innovation networks and is confronted by financing problems. Examples of CoPS include aircraft carriers and aero-engines. Similar to the semiconductor manufacturing equipment industry, that of aero-engines is characterized by various fundamentally different technologies, an extremely high amount of components, a highly specialised supplier base, an abundance of networks, high interrelatedness of sub-systems/components, soaring R&D costs, and significant uncertainty regarding the success of development programmes. Key suppliers often become so-called risk and revenue partners (bilateral agreements) and buy stakes in development programmes of aircraft engines (Acha et al., 2007; Brusoni and Prencipe, 2011; Figueiredo et al., 2008; Luz and Salles-Filho, 2011). However, the character of these financial deals is different from that in the semiconductor manufacturing industry. In the aero-engine industry, key suppliers buy a stake in development programmes and, thereby, reduce the financial risk for the engine manufacturers, while in the semiconductor manufacturing industry system integrators provide critical suppliers with financial resources to reduce their development risk.

The finance literature is hardly concerned with financing beyond the boundaries of the single firm (Brealey et al., 2006), with the exception of project finance. According to Esty and Megginson (2003, p. 39), "project finance is defined by the creation of a legally independent project company financed with non-recourse debt for the purpose of investing in an industrial asset". Project finance operates with a high debt-to-total equity of 70% on average (Esty, 2004). Because of the project companies' high levels of debts and the non-recourse character of the debts, lenders are only willing to provide loans if the company's cash flows are quite predictable. However, high-risk development projects do not have predictable cash flows (Yescombe, 2007). Moreover, the few empirical studies on project finance that exist (Dailami and Hauswald, 2007; Esty and Megginson, 2003) do not study the interactions between the actors involved. More recently, Boone and Ivanov (2012) have at least investigated the possible spill-over effects of the bankruptcy of an alliance or network partner on the valuation and operating performance of the others. While these insights are not directly relevant in light of our specific interest, Leitner (2005) answers our research question to some degree. The researcher modelled a scenario in which liquid banks might bail out illiquid banks with which they are financially interwoven to prevent the breakdown of the entire financial network. However, the author focuses on developing a model for the optimal network size for a possible bailout instead of determining the type of coordinative practices actors actually use to address such network problems. The case we are looking at also differs in another important respect: instead of being illiquid, the firms only lack the ability or willingness to finance an innovation on their own.

Furthermore, venture capital (VC) firms are known for financing the high-risk development of small entrepreneurial firms (Gompers, 1995) and taking on an organizing role in networks (Lindsey, 2008). Thus, VC firms could help directly and indirectly to fill the roadmap gaps. However, the characteristics of the gaps in the chip industry's roadmap are not conducive to the type of start-ups that VCs prefer, as VCs typically have a limited time horizon and usually intend to exit their investments after no more than 5 years (Chesbrough, 2000; Harding, 2002). With regard to the system technology under scrutiny, it is difficult to predict when VCs will be able to exit their investments because the conventional technology, optical lithography, has been extended constantly (Henderson, 1995; Linden et al., 2000; Appleyard et al., 2008; Sydow et al., 2012). Additionally, the semiconductor industry has been consolidating in recent years (The Economist, 2009), and the pool of potential customers for any new manufacturing technology has