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Uncertainty, networks and real options☆

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ABSTRACT

Two pervasive features of industries experiencing rapid technological progress are *uncertainty* (with regard to the technological feasibility and marketabilility of an innovation) and *networks* (the dense web of research alliances and joint ventures linking firms to each other). This paper connects the two disparate phenomena using the notion of *real options*. It visualizes firms as nodes and the links connecting them as call options that give each pair of interlinked firms the right, but not the obligation, to sink additional resources into a project at some future date conditional on favorable technical/market information. The formation of networks is endogenous as firms establish links with others by appraising their value using option pricing methods. Our model explains the following: why networks are particularly ubiquitous in industries that are subject to high uncertainty; why networks often display an interconnected "hubs and spokes" architecture; why small (or peripheral spoke) firms often sink resources into relatively higher risk higher return investment projects (and those too with only large, or hub firms); and why so many research alliances are continuously formed and dissolved. Our paper also outlines the conditions under which ex-ante symmetric firms end up ex-post forming complex asymmetric networks.

1. Introduction

There are two pervasive features of industries experiencing rapid technological progress. The first is *uncertainty*, both technological (uncertainty regarding whether the investment will yield a successful innovation) and market (uncertainty regarding the marketability of the innovation). The second feature is *n* etworks, which refers to the linkages among firms in the form of strategic alliances and joint ventures to jointly conduct R&D activities and share the benefits of cooperation. Recent examples of networks in such industries include the strategic partnerships of Sony and Toshiba to produce the sophisticated chips at the heart of Blu-ray and HD DVD formats, the partnerships of Boeing and of Airbus with multiple suppliers and buyers in developing their new, composite material airplanes, and the partnerships of large pharmaceutical companies with smaller biotechnology firms. This paper examines the relation between uncertainty and networks using the concept of *r* eal options.

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There is already a significant literature that examines the endogenous formation of research networks (e.g. Bloch, 1995; Yi, 1998; Yi and Shin, 2000; Goyal and Moraga, 2001; Goyal and Joshi, 2003; Billand and Bravard, 2004). This literature examines network formation in a *deterministic* framework in which research alliances stimulate product/process innovations that reduce costs of production for participants non-randomly as a function of the alliance's size. The tension between the benefits from cost-reduction and the costs of enlarging the size of the alliance shapes the strategic incentives of firms and determines the equilibrium architecture of networks. The deterministic formulation has contributed significantly to our understanding of research networks. However it also misses some important empirical facts[1]:

1. High-tech fast-evolving competitive environments, such as those of biotechnology/pharmaceuticals and information technology, are characterized by uncertainties regarding both the technical feasibility of ideas for new products/processes and their economic viability in the market.
2. Research networks are particularly ubiquitous in industries characterized by such uncertainty.[2]
3. Firms choose projects that differ widely with respect to their risk characteristics. Firms that are smaller and more peripheral than larger and more central firms often pursue higher risk projects.
4. Research networks are characterized by a high degree of link formation and link destruction activity as the uncertainty resolves.

These empirical facts suggest that the incentives shaping the network architecture in industries characterized by rapid technological progress depend in a fundamental way on the underlying uncertainty. This link between uncertainty and network architecture is *a priori* excluded in the received deterministic literature on endogenous research networks.

The simple model of network formation that we propose captures the main empirical facts quite nicely. *The prevalence of networks in an environment of high uncertainty is explained by viewing research networks as a set of nodes* (*corresponding to firms*) *and links between nodes* (*real options between firms*). In the presence of uncertainty, a firm cannot be sure whether any one investment in a new product/process will be successful. Firms diversify the risk by making relatively small initial investments in a number of R&D projects and then waiting to commit significant resources only into those projects that are deemed favorable on the basis of new information. This flexibility increases the ability of firms to better allocate scarce resources to profitable projects. Firms typically identify and enter promising new fields quickly, thus jumping early on the learning curve. All firms are, of course, limited in their ability to realize these objectives by internal resource constraints. This is precisely where networks play an important role. In high-tech sectors, research partnerships serve as technology search engines: firms unable to justify heavy investments in fluid, high-risk, high-potential technological areas can form multiple research partnerships to explore the field and create opportunities for more investment there in the future (Hemphill and Vonortas, 2003). In addition to learning about new opportunities, research partnerships also help share research costs, share technological and market risk, access complementary resources, access markets, and increase strategic flexibility.[3] In sum, networks allow firms to diversify and expand their technology search space collectively in terms of pursuing multiple and bolder (high risk, high return) research projects than what they otherwise could by operating alone due to paucity of resources.

In the uncertainty framework therefore, in contrast to the deterministic models, an alliance between any two firms may not actually reduce the costs of either. Rather, the alliance can be perceived as an agreement to pursue an R&D project jointly by making an initial investment and retaining the option of revisiting the project at a later date to sink more resources on the basis of new information. This view of two firms forging an alliance is analogous to two firms agreeing to buy a call option. By making an initial joint investment, the two firms have the right, but not the obligation, to commit to a joint R&D project (i.e. exercise the option) at some future date and buy the entitlement to the future stream of profits from this project. These call options, when applied to investment in new products/processes, are called *real options*. The novel

[1] Examples of technology-intensive alliance strategies across various sectors that exhibit such phenomena include the following: the alliance between Hewlett-Packard and Microsoft that pools the companies' systems integration and systems software skills, respectively, to create technology solutions for small and big customers; the alliance between the biotechnology firm Abgenix and the pharmaceuticals company AstraZeneca that combines the strengths of the former in discovering new drugs and the familiarity of the latter with the FDA approval process; Pfizer's alliance with Warner-Lambert for the cholesterol decreasing drug Lipitor in the mid-1990s, the first step of a buy-out; the FreeMove alliance between T-Mobile, Telefonica Moviles, Telecom Italia Mobile and Orange announced in 2003 for a "unified service offering" to both their business and consumer customers; the Starmap alliance between O2, Amena, One, Pannon GSM, Sunrise, Telenor Mobile, and Wind to provide seamless, enhanced voice and data solutions for business and consumers across Europe; the joint ventures Alcatel Alenia Space and Telespazio Holding between Alcatel and Finmeccanica in 2005 to consolidate leadership in the telecommunication satellite systems and services, and to acquire a strong position in the most important European programmes such as Galileo and GMES.

[2] For example see Caloghirou et al. (2004, 2006), Gulati (1998), Hagedoorn et al. (2000), Kogut (2000), Nohria and Eccles (1992) and Powell et al. (1996).

[3] For a survey of this literature see Caloghirou et al. (2004), Hagedoorn et al. (2000), Jankowski et al. (2001) and Vonortas (1997). This networking view is also supported by the strategies of some leading companies. For example, in the ten years to 2004, Cisco had entered into more than 100 alliances (and had acquired 36 companies). Internal development of products, acquisitions and alliances are considered alternatives. When there is a high degree of uncertainty around technologies, or when they are not critical, Cisco uses alliances. Moreover, Procter & Gamble Co. has transformed its traditional in-house R&D process into an open-source innovation strategy it calls "connect and develop". The new method can be described as embracing the collective brains of the world. It has made it a goal that 50 percent of the new products come from outside P&G's labs. For this purpose, it taps networks of inventors, scientists and suppliers for new products that can be developed in-house.