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The evolution of R&D networks

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ABSTRACT

We study the evolution of R&D networks in a Cournot model where firms may lower marginal costs due to bilateral R&D collaborations. Stochastically stable R&D networks exhibit the dominant group architecture, and, contrary to the existing literature, generically unique predictions about the size of the dominant group can be obtained. This size decreases monotonically with respect to the cost of link formation and there exists a lower bound on the size of the dominant group for non-empty networks. Stochastically stable networks are always inefficient and an increase in linking costs has a non-monotone effect on average industry profits.

1. Introduction

The formation of R&D networks, where firms cooperate with respect to their innovative activities, is an important feature of many industries (see e.g. Hagedoorn, 2002; Powell et al., 2005; Roijakkers and Hagedoorn, 2006). In many cases the firms cooperating on the R&D level are competitors in the market, which gives rise to intricate strategic considerations when selecting R&D cooperation partners. As has been highlighted in the literature (e.g. Hagedoorn, 2002) many firms adjust their set of R&D cooperation partners over time, thereby inducing a dynamic evolution of the R&D network in their industry. In spite of the substantial empirical work showing the importance of R&D network, theoretical analyses of the dynamics of R&D networks and the structure of networks emerging from such dynamics is sparse. In this paper we contribute to the theoretical understanding of the factors determining the structure of R&D networks emerging from (myopic) network adjustment decisions of firms. Furthermore, we examine how such emerging structures compare to efficient networks and characterize the effects of changes in parameters, like the costs of R&D cooperation, on industry profits and welfare induced by the long run R&D networks.

We study the evolution of R&D networks in a standard Cournot oligopoly setting, where it is assumed that in each period all firms in the industry offer a homogeneous good. Firms might engage in costly R&D cooperation and the larger the number of a firm's cooperations the lower are its marginal production costs. In order to keep our model tractable we assume that only

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the *current* number of R&D cooperations is relevant for the current marginal costs of a firm rather than all cooperations it had in the past. This assumption captures in a simplified way that, because of the evolution of the properties and production processes of the (homogeneous) good offered on the market, past R&D cooperations are of limited value compared to current ones and therefore the relative number of current R&D cooperations of a firm determines its cost advantages respectively disadvantages relative to its competitors. In each period the whole set of current R&D cooperations is common knowledge and all firms simultaneously choose their output quantities, which leads to the Cournot equilibrium outcome under the current marginal cost profile.

The evolution of the R&D network is modeled as a perturbed myopic best reply dynamics similar to Jackson and Watts (2002) for a survey on dynamic models of network formation, see Hellmann and Staudigl (2013). Every period one existing or potential new link is randomly chosen to be reviewed by the two involved firms. They compare their current profits with and without this R&D cooperation and choose the more profitable option with high probability, whereas with low probability they make a mistake. Based on the strong uncertainty involved in R&D projects and R&D cooperations this formulation assumes that firms are not able to predict future changes in the R&D network and the effects of their R&D decisions on the evolution of this network. The stochastic process describing the dynamics of the R&D network has a unique long run distribution and, relying on the concept of stochastic stability, we characterize the networks which are observed most of the time when the probability of mistakes is small.

A static version of the model considered here has been analyzed in a seminal contribution by Goyal and Joshi (2003), who characterize the structure of pairwise Nash stable (PNS) R&D networks in this setting. They show that the PNS networks exhibit the dominant group architecture (with one completely connected group and all other firms isolated). However, a wide range of these types of networks (with respect to the size of the dominant group) may be PNS. And although the sizes of the dominant group are sensitive to the cost of link formation, there is no unique prediction with respect to the networks which will be observed. Moreover surprisingly, the minimal size of the component in a non-empty network is increasing in the cost of link formation for a certain cost range. In a related setting of directed R&D networks and Cournot competition Billand and Bravard (2004) obtain stable networks with a similar structure in a sense that a subset of nodes is heavily connected, whereas the other nodes do not form own links. In these models, the efforts invested in R&D are exogenous. Goyal and Moraga-Gonzalez (2001) present a model of R&D networks where each firm can choose the efforts devoted to R&D. Related to this approach Goyal et al. (2008) allow for in-house and partner specific investments. While it is not possible to fully characterize the stable network architectures in these two models, equilibrium investments in R&D and implications for welfare are studied.

Due to the large sets of stable networks, these static treatments of R&D network formation allow only very limited insights into the structure of networks emerging from a dynamic adjustment process. In the main result of our paper, we characterize the networks which are observed most of the time in our dynamic process, i.e. the set of stochastically stable R&D networks in our Cournot oligopoly setting. Trivially, they also exhibit the dominant group architecture. However, we find that the stochastically stable networks are typically unique (with respect to the size of the dominant group) and the size of the dominant group is monotonically decreasing in the cost of link formation, solving the puzzle of non-monotonicity in Goyal and Joshi (2003). Further, we show that there exists a threshold of the dominant group size, below which only the empty network can be stochastically stable.

This characterization result of stochastically stable networks has interesting connections to analytical findings on efficient networks; e.g. in a similar two stage game, Westbrock (2010) studies the efficient networks and also concludes that either the empty network is efficient or there exists a lower threshold on the size of the dominant group for efficient networks to have the dominant group structure. Our findings imply that for relatively large linking costs the structure of the stochastically stable networks differ from that of the efficient ones. For relatively small linking costs both the stochastically stable and the efficient networks have dominant group structure, where however numerical analysis suggests that both generically differ with respect to size such that stochastically stable networks are under-connected.[1]

Since the concept of stochastic stability allows us to select generically unique R&D networks for all values of the linking costs, we are in a position to study the effects of changes in the linking costs on consumer surplus and industry profits under consideration of the resulting changes in structure of the emerging R&D networks. It turns out that whereas consumer surplus moves in the intuitively anticipated direction, i.e. increasing linking costs imply decreasing consumer surplus, a non-monotone U-shaped relationship between linking costs and average industry profits emerges. In particular, for relatively high linking costs associated with small dominant group sizes, an increase in these costs induces an increase in the firms' profits.

Dynamic models of R&D network formation have recently been provided in different economic frameworks (see e.g. Baum et al., 2010; König et al., 2011). The economic environment in these contributions differs substantially from the Cournot oligopoly setting considered here and in Goyal and Joshi (2003) and Billand and Bravard (2004). Therefore, the stable networks do not exhibit the dominant group structure and these dynamic studies do not provide an indication of the structure of R&D networks emerging in the long run in the standard Cournot setting. In particular, a dynamic theory of

[1] Under-connected networks are contained in welfare better networks, e.g. efficient networks, see Buechel and Hellmann (2012).