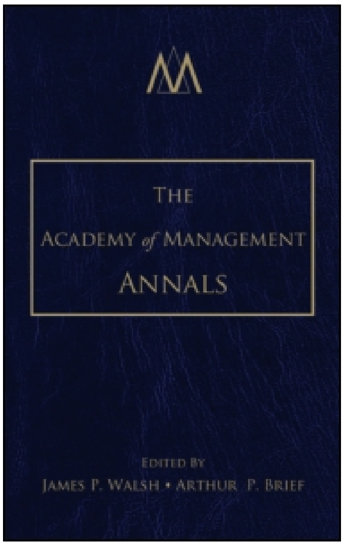

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Chapter 1: Moving Beyond Schumpeter: Management Research on the Determinants of Technological Innovation

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Moving Beyond Schumpeter:
Management Research on the Determinants of Technological Innovation

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Abstract

Schumpeter's conjecture that large monopolistic firms were the key source of innovation in modern industrial economies has been the underpinning for much work on the topic of innovation. In this review paper we consciously move beyond the Schumpeterian tradition of focusing on firm size and market structure as the primary determinants of innovation to identify a broader set of innovation determinants that have been investigated by the management literature. We make a distinction between innovative efforts and innovative output and for each of these outcomes we group the determinants

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of innovation into four broad headings—industry structure, firm characteristics, intra-organizational attributes, and institutional influences. We examine four aspects of the industrial structure and how they influence innovation: the horizontal market structure which reflects the influence of competition and collaboration, as well as the role of buyers, suppliers and complementors. Under the rubric of firm characteristics, we consider the many externally observable attributes of a firm such as its size, scope, access to external sources of knowledge such as through alliances, and performance. Under the heading of intra-organizational attributes we look at the inside of the firm, the firm's organizational structure and processes, corporate governance arrangements including compensation and incentive structures, the backgrounds of managers, and organizational search processes. Finally, we consider two significant sets of institutional influences, the supply of science (wherein we also examine the nature and degree of science–industry relationships), and the appropriability regime. In each setting we try to structure the existing literature to identify the core theoretical mechanisms as well as empirical support for those mechanisms. We explicitly focus on the management literature in this area recognizing that the work of economists is being summarized in other such reviews. However, we have consciously tried to use terminology and organizing structures that should be familiar to both economists and management scholars and hope to encourage greater conversation and cross-fertilization between these two groups. To facilitate this outcome we especially emphasize some areas where management literature has developed the most (e.g., alliances and networks) but then integrate the literature in these areas within the broader rubric of work in the economics tradition.

Introduction

Understanding the determinants of technological innovation has been an important and fecund source of inquiry in the management and economics literatures. Although economists such as Solow and Schumpeter are most memorably associated with raising the fundamental questions on this topic, the issue has also sparked immense interest in the management area, broadly encompassing the fields of strategy, organizational theory and organizational behavior. In this essay, we take stock of this management literature. We examine the most important questions raised in this literature, discuss the state of knowledge as represented by the answers so far obtained in both theory and empirical terms, and identify what we perceive to be the most significant unasked or unanswered questions in the area.

Consistent with the title of this survey paper, we constrain our review on some important dimensions. Most notably, we focus our attention on the management literature in this area with limited reference to the work done on these questions by economists. This design choice is underwritten by two considerations. First, the topic is simply too huge to be acceptably covered in a single survey paper if the work of economists in this area is to be recognized in any serious fashion. Second, there are several excellent surveys of the economics work in this terrain that have been or are being written (Arora & Gambardella, 2008; Cohen, 1995; Cohen & Levin, 1989; Gilbert, 2006). These surveys, by design, focus on the work of economists rather than the management literature. Thus, focusing the current work on the management literature complements these efforts while also permitting a nice and (fairly) clean division of labor.

A second notable distinction with respect to the scope of this article is that it moves beyond Schumpeter in its review of work in the area. Schumpeter's basic questions relating innovation to firm size and market structure have dominated this topic for the last several decades. Although the contributions of the studies that have examined the Schumpeterian questions are immense, in this survey, we explicitly look beyond those studies because of the aforecited complementarity and division of labor considerations. The surveys mentioned previously already cover the market-structure and firm-size implications of innovation well; however their coverage of the management literature, which has focused on many additional determinants of innovation, is limited. Of course, that noted, we will touch upon the Schumpeterian questions briefly, both to highlight the influence of these additional innovation determinants and to position those determinants within this broader and more traditional rubric.

A third notable distinction, partially discernable from our title, is that we focus on the generation of technological innovations. This choice limits our discussion in two ways. One, we do not consider research (Aiken & Hage, 1971; Collins, Hage, & Hull, 1988; Hage, 1999) that uses a broader definition of innovation—"the adoption of an idea or behavior that is new to the organization" (Hage, 1999, p. 599)—and thus focuses on the diffusion of innovations. Second, this paper also leaves out studies that focus on non-technological innovations such as administrative or organizational innovations. This is not to suggest that these topics are not important. On the contrary, the innovativeness of organizations is as much dependent on their adoption of new ideas as it is on the creation of new ideas (Cohen & Levinthal, 1990; Hage, 1999). Rather, our choice is motivated by space constraints and the fact that existing reviews addressing the broader issue of organizational adaptability already cover this domain (Damanpour, 1991; Hage, 1999).

Another important distinction is to note that this survey is primarily written to highlight the key theoretical mechanisms that have been identified by management research on innovation. A literature review can vary in its emphasis between a review of the key empirical findings and hence the identification of key stylized facts about a phenomenon versus its summary of the key theoretical mechanisms that have been identified by the literature (though they may not all have been tested or validated). Although this review touches on both aspects, theoretical novelty and empirical validation, its emphasis is on identifying the theoretical mechanisms and relationships studied in the literature rather than establishing an assembly of empirical generalizations that we can embrace. This decision has been made for two reasons. First, the management field has not generally emphasized replication and purely empirical studies are difficult to publish in the top journals. Accordingly, most of the research has focused on identifying some theoretical novelty as a necessary precondition for writing the paper. The advantage of this is that the literature identifies many interesting theoretical nuances and possibilities. The disadvantage is that most of those nuances are validated relatively rarely beyond the original study. Second, in the context of innovation, to attempt to deliver on both, the novel explanations identified and the extent of empirical support provided to each one, would turn out to be an impossibly big task for an article-length survey. Hence, one way to interpret the mechanisms identified in this survey are to think of them as plausible explanations of a given outcome that have usually been demonstrated in an observed sample (or few samples) rather than as "final" empirical realities that have been reached after robust investigation with multiple samples and approaches. Of course, for some of the bigger variables such as market structure, size, role of alliance ties, there are multiple studies that provide support for a given point of view. However, this empirical wealth is not available for all issues.

We highlight the broad structure of this essay next. In this paper, we make a distinction between *innovative efforts* and *innovative output*. Research on the determinants of innovation has used both innovative outputs, and innovative inputs as measures of innovation (Cohen & Levin, 1989). The two factors differ (Fisher & Temin, 1973; Henderson, 1993; Link, 1980). The issue of innovative inputs or efforts is a question of incentives (Tirole, 1988) and wherewithal (Galbraith, 1952; Schumpeter, 1942): what factors affect the incentives and the ability to support research? The issue of innovative output on the other hand is concerned with research productivity (Kamien & Schwartz, 1975; Kamien & Schwartz, 1982): given a research effort, however determined, what factors determine the resultant level of output? Both questions are important in that optimal resource utilization requires both appropriate allocation of resources and maximal productivity of the allocated resources (Majumdar, 1995, 2000). Nevertheless, to the extent that these are different questions, and may therefore have different answers, there is a need to distinguish between them (Henderson, 1993).

By making this distinction, we suggest that the issues we study can be usefully conceived of in terms of two equations, one reflecting *innovative effort* and its determinants, and the other reflecting *innovative output* and its determinants:

$$\text{Innovative Effort} = f = (Z_e) \quad (1)$$

where Z_e is a vector of covariates affecting the innovative effort of a firm.

$$\text{Innovative Output} = f = (Z_o) \quad (2)$$

where Z_o is a vector of covariates affecting the innovative output of a firm.

We call Equation (1) the *research production function* as the output of this function is innovative effort, or research.[1] We follow past research in calling the Equation (2) the *innovation production function*, as its output is innovation (Kamien & Schwartz, 1982; Reinganum, 1984). We structure our review to address these two questions. Of course, this distinction is an expositional simplification in that there could be, and indeed are, factors that influence both simultaneously. For instance, the presence of knowledge spillovers is likely to influence both the decision to conduct research and development (R&D) as well as the productivity of the conducted R&D. Nevertheless, for analytic simplicity we use this partitioning. Clearly, the evolution of technology, more generally, encompasses the study of outcome variables beyond just these two (see, for example, Abernathy & Clark, 1985; Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Romanelli & Tushman, 1994; Tushman & Anderson, 1986; Utterback & Abernathy, 1975) and includes many other behavioral and economic phenomena but we take a rather firm-centric view here and limit our attention to specific factors that we highlight later.

For each of these questions, we group the determinants of innovation into four broad headings—industry structure, firm characteristics, intra-organizational attributes, and institutional influences (see Figure 1.1). We examine

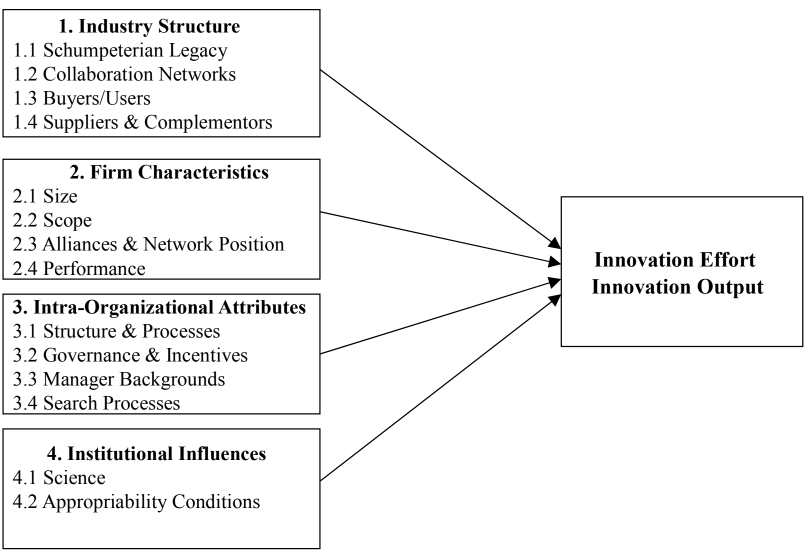

Figure 1.1 Layout of the Review.

four aspects of the industrial structure and how they influence innovation: the horizontal market structure which reflects the influence of competition and collaboration; the role of buyers; and the role of suppliers and complementors. Under the rubric of firm characteristics, we consider the many externally observable attributes of a firm such as its size, scope, access to external sources of knowledge such as through alliances, and performance. Under the heading of intra-organizational attributes, we look at: the firm's organizational structure and processes; corporate governance and compensation and incentive structures; the background of managers; and organizational search processes. Finally, we consider two significant sets of institutional influences, the supply of science (wherein we also examine the nature and degree of science–industry relationships), and the appropriability regime. This ordering (largely) follows the temporal development of the literature from its emphases on market structure and firm size to the identification of broader intra-firm and extra-industry sources of innovation.

However, given the prominence of the Schumpeterian arguments, before we "explode" the innovation production function and research production function to include these many influences, we first examine the Schumpeterian theses briefly. Through this examination, we note that a close reading of the Schumpeterian arguments quite naturally opens up a consideration of these many additional arguments that should help us understand better the generation of innovations. As another caveat, we note that there is a significant management literature that has developed around the geography of innovation. Clearly, that has a bearing on innovative efforts and innovative output. However, simply for reasons of length more than anything else we do not cover that literature here and the work of scholars in that area is omitted (for coverage of this, please see Agrawal & Cockburn, 2003; Almeida & Kogut, 1999; Chung & Alcacer, 2002; Feinberg & Gupta, 2004; Feldman, 1999; Fleming, Mingo, & Chen, 2007; Gittelman, 2007; Gupta & Govindarajan, 2000; Jaffe & Trajtenberg, 1999; Rosenkopf & Almeida, 2003; Zhao, 2006). More generally, the broad scope of this survey implies that many excellent pieces have been omitted as we are often touching upon only a few of the studies in a given topic area. We apologize in advance for those many acts of omission. We also gratefully acknowledge the intellectual influence of the many past reviews of the innovation literature (Baldwin & Scott, 1987; Cohen & Levin, 1989; Cohen, 1995; Encaoua, Guellec & Martinez, 2006 ;Gilbert, 2006; Kamien & Schwartz, 1975, 1982; Mone, McKinley and Barker, 1998; Reinganum, 1989).

1. Industry Structure and Innovation

1.1 The Schumpeterian Legacy: Market Structure and Innovation

Introduction. Any survey on the determinants of technological innovation must at some stage confront "the Schumpeterian legacy" (Baldwin &

Scott, 1987). Prior to the publication of Schumpeter's (1942) classic, technical advance, while being recognized as critical to development, had in general been treated as exogenous by researchers of markets and firms (Cohen & Levin, 1989; Kamien & Schwartz, 1982). Schumpeter related both firm size and market structure to innovation and thus drew attention to the endogeneity of technical change. Schumpeter's central assertions had a significant impact on economic thought and inspired an immense body of theoretical and empirical literature, most of it focusing on developing and testing the two *Schumpeterian hypotheses*: (1) innovation increases with market concentration (Cohen & Levin, 1989); and (2) innovation increases more than proportionately with firm size. We focus here on the first relationship. In a later section of this review, where we examine the role of firm characteristics, we address the firm-size issue.

Even though Schumpeter is associated with some of the most memorable phraseology relating large, monopolistic firms to innovation ("…big business may have had more to do with creating that standard of life than keeping it down…", "…add as many mail-coaches as you please, you will never get a railroad by so doing…") his depiction of the links between innovation and market structure was at best imprecise (see Baldwin & Scott, 1987; Cohen & Levin, 1989; Schumpeter, 1942, Introduction). The task of formulating specific hypotheses to clarify the Schumpeterian arguments has therefore largely been left to subsequent researchers with the natural consequence that multiple interpretations and tests of these relationships have been proposed and tried out (Cohen & Levin, 1989). Indeed, Cohen and Levin (1989) note the market-structure and innovation literature (conjoined with the size–innovation relationship) has become "the second largest body of empirical literature in the field of industrial organization, exceeded in volume only by the literature investigating the relationship between concentration and profitability".

However, this vast body of research has, in general, proved inconclusive with market structure not being found to be strongly or consistently related to innovation (Baldwin & Scott, 1987; Cohen & Levin, 1989; Kamien & Schwartz, 1982). Although methodological problems, such as non-random samples, poor controls, endogeneity problems, and quality of data, are partly responsible for this lack of consensus, part of the confusion is due to lack of conceptual clarity (Cohen & Levin, 1989; Gilbert, 2006). One manifestation of this conceptual confusion was mentioned earlier: the failure to distinguish between innovative efforts and innovative output in empirical tests of the hypotheses (Fisher & Temin, 1973; Link, 1980). A second problem has been the preoccupation with looking for monotonic relationships between innovation and market structure, and a consequent neglect of the possibilities of more complex patterns of relationships between these variables (Cohen & Levin, 1989; Markham, 1965; Nelson, Peck, & Kalachek, 1967). A third explanation of inconsistent results in the market structure–innovation relationship emerges from the possibility of omitted variables. Although the number and size distribution of firms is an important structural feature of an industry, several other structural features are also likely to influence the incentives to innovate and the productivity of the innovation efforts in an industry. Most importantly, industry structures may differ in terms of the presence, activity and size-distribution of buyers, suppliers and complementors (Brandenburger & Nalebuff, 1996; Porter, 1980). Consideration of these roles may lead to a more nuanced understanding of problem of innovation and industry structure. Finally, while measuring market structure in terms of monopoly versus perfect competition that has been favored by this literature may capture the incentive effects of rivalry between players, it leaves unexplored another possible dynamic of the relationship between horizontally related firms—that of collaboration. A closer examination of the mechanisms by which market structure effects are supposed to operate highlights the importance of these concerns and also helps to establish the relationship of the other determinants of innovation to the Schumpeterian schema.

Market structure and the research production function. A close examination of the arguments relating market structure to innovation suggests that its effects apply primarily through incentive and wherewithal arguments. Market power has been argued to both enhance (Schumpeter, 1942) and depress the incentives to invest in innovation (Arrow, 1962; Scherer & Ross, 1990). We discuss the major theoretical arguments from both sides of the debate briefly. For a more detailed discussion, we refer the reader to the two excellent reviews on innovation mentioned earlier (Cohen, 1995; Gilbert, 2006). What is notable is that, since the main effects are countervailing, the final effect of market structure on innovative effort is unclear, the Schumpeterian conjectures notwithstanding. Indeed it is not even clear whether the relationship can reasonably be expected to be linear. Innovation incentives may go up with market power to a certain point and then dip again. Recognizing this theoretical problem makes it easier to reconcile to the different findings in the literature. Empirically, Scherer (1967) found an "inverted-U" relationship between R&D intensity and concentration. This has been replicated in other studies as well (see Cohen, 1995 for details).

Three main arguments have been used in the literature to suggest that superior market power provides greater incentives (or wherewithal) to innovate. However, each of these arguments is itself subject to criticism leaving the final prediction somewhat indeterminate. We examine each argument and its related counterargument(s) briefly.

The first argument relating concentration to innovative effort suggests that market dominance provides firms with profits and security to finance risky activities such as innovation (Baldwin & Scott, 1987; Cohen, 1995; Schumpeter, 1942). Note that this formulation presumes imperfect capital markets, as, in well-functioning capital markets, existing profitability should not be a precondition for innovation efforts (Cohen, 1995). To the extent that industries may differ in the availability of risky capital or the efficiency with which it is allocated there may be little or no observed empirical relationship between market structure and innovation across industries. Further, a deeper consideration of the security argument suggests an opposing effect of market dominance on innovation. The Hicksian argument that "the best of all monopoly profits is a quiet life" suggests that the "security" provided by a monopoly may be carried too far. Monopolies that are in a comfortable position with little immediate threat from competition may feel less "pressured" to invest in R&D and innovate (Cohen, 1995; Scherer & Ross, 1990).

The second main argument suggests that to the extent that firms are under the threat of losing their market power due to the gale of creative destruction (Schumpeter, 1942) ushered in by innovative entrants (Christensen & Bower, 1996; Henderson & Clark, 1990), monopolies have more to lose than competitive firms and therefore are more motivated to invest in innovations to preempt competition. A direct counterargument to this Schumpeterian proposition is provided by the "Arrow replacement" effect that argues that monopolies have fewer incentives to invest in innovation because the innovation may cannibalize their existing offerings in the market and thus simply move the firm from one monopoly position to another. Thus, all that the monopolistic firm can hope to gain from innovative effort is the difference between the monopoly profits with the new innovation and the monopoly profits with the old offering. The competitive firm, on the other hand, gains the full amount of monopoly profits from the innovation since it has no monopoly profits to lose from its earlier offering. Hence, competitive firms have a greater incentive to innovate. Again it is notable that the sign of the predicted relationship is unclear. In a Schumpeterian world one would see a positive effect of market dominance on innovative effort but in an Arrovian world the opposite might emerge. Note that subsequent research has highlighted further conditions that support one logic or the other (see Gilbert, 2006), making the exercise of a simple search for a positive relationship even trickier.

Indeed, consideration of the broader economics and management literature suggests that the mechanics of the relationship between market power and innovation may be quite complex. For instance, at low levels of market power, firms may feel threatened with the potential gale of creative destruction and be motivated to invest in preemptive innovation (Gilbert & Newbery, 1982). However, as the market power of a firm increases, its likelihood of being swept away by entrants decreases because of two reasons. One, it has a bigger buffer to take such shocks and recover (Levinthal, 1991). Second, the firm can use its superior resources to fight off or buy off the challenge. Further, potential competitors may also prefer a buy-out to competing with a dominant incumbent. Thus, at high levels of market power, firms may see a reduction of their incentives to innovate directly, rather leaving that task to others that they subsequently eliminate through buy-outs or control of complementary assets. In one of the few management contributions to this debate (which has largely occurred between the economists) yet another mechanism was identified by Conner (1988) who showed that monopoly firms could invent new technologies but strategically choose to launch them only when threatened by a challenger.

The third main argument presented to support a positive link between market dominance and innovative efforts is that by creating path-breaking innovations, firms can alter the market structure and gain market power which ensures superior profits. This lure of market power provides incentive to invest in R&D (Cohen, 1995; Cohen & Levin, 1989; Schumpeter, 1942). Note that the market power referred to in this argument is ex-post market power while the market power in the first and second reasons referred to is ex-ante market power (Cohen, 1995). Thus, empirical tests that relate market power to innovation and regress innovation against some measure of market structure (the most common research design in the literature) are usually only testing arguments 1 and 2. Indeed, it is difficult to identify literature that has tightly tested this version of the proposition directly.

The key conclusion to be drawn from this exercise is simply that the basic Schumpeterian market structure arguments are not strongly unidirectional. Hence, identifying empirical trends in broad cross-sections of industries may be an exercise of only limited value, because underlying contingencies are likely to determine the effects of concentration in any given empirical context. Rather, an alternate line of attack might be to look for empirical contexts that allow individual contingencies to be captured effectively and thus help to elaborate a more nuanced understanding of the relationship between market structure and innovation.

The above arguments, both those that suggest market power provides incentives to innovate and those that suggest otherwise, are predicated on the assumption that the firms know who their competitors are. Even the economic models that take the uncertainty and cumulativeness of innovation into account (Doraszelski, 2003; Harris & Vickers, 1985; Reinganum, 1983, 1985) assume that the players know who they are competing with and in some cases (Doraszelski, 2003), how much the competitors are investing in innovation. Sociological theories of markets (Porac, Thomas, Wilson, Paton, & Kanfer, 1995; White, 1981) suggest that these assumptions may be tenuous. Firms may regard only a part of the competition as relevant (White, 1981) and model their actions on the cues provided by the members of the subset (White, 1981). This opens up the possibility that competition is asymmetric. Porac et al. (1995), studying the Scottish knitwear industry, found that rivalry was defined based on firms' perceptual map of the industry. Central firms were considered rivals by firms that they themselves did not consider as rivals, where centrality refers to a structural position of firms in the network. The firm's incentives to invest in innovation may, therefore, be more dependent on what they consider the competition to be rather than what the actual level of competition is. The consequences of this on innovation motivations are still unexplored.

Market structure and the innovation production function. While a number of arguments relate market structure to innovation efforts, none of those arguments provide any reason to believe that possessing or lacking market power should have any impact on the *productivity* of the research effort. Hence, market power, in spite of its prominence in the Schumpeterian schema does not find a place in the innovation production function, at least in the Schumpeterian sense.

An argument, raised subsequently in the literature, suggests an alternate rationale for a market structure effect on innovative productivity: insulation from competitive pressures breeds bureaucratic inertia and therefore discourages innovation in oligopolistic market structures (Majumdar & Venkataraman, 1993; Scherer & Ross, 1990). However, the conceptual basis for this argument is not fully convincing when applied to the issue of innovative productivity. Although oligopolistic market structures could arguably lead to lower *levels* of innovative efforts (Majumdar & Venkataraman, 1993; Tirole, 1988), it is not clear why they would lead to poorer *productivity* of these efforts. The oligopolist may gain something from not making research investments, but clearly the oligopolist gains nothing from poorly utilizing the money that is being invested. Nevertheless, an X-efficiency rationale may still be valid if one assumes that a firm with market power is, in general, likely to be less conscious about costs than a competitive firm, and may thus waste resources relative to a competitive firm (Kamien & Schwartz, 1982; Majumdar, 1995). However, even this version of the argument suffers from two critical weaknesses. First, pure monopolies are relatively rare in practice and sustaining "soft competition" or "cartelizing" arguments is difficult in an oligopoly, even one composed of very few firms (Stigler, 1964). Both theory and empirical evidence indicate that oligopolies which have at least a few firms are characterized by relatively fierce competitive intensity, especially on dimensions other than price (Fershtman & Gandal, 1994; Grabowski & Baxter, 1973; Tirole, 1988). Further, in industries characterized by rapid technological progress, competition in research is likely to be the primary basis of competition, a proposition endorsed by none less than Schumpeter himself (Schumpeter, 1942), and found to hold in subsequent empirical research (Comanor, 1965; Grabowski & Baxter, 1973; Grabowski & Mueller, 1978; Majumdar & Venkataraman, 1993). Hence, an assumption of X-inefficiency in the research process may be supported with only limited confidence in any industry that is not a strict monopoly or is characterized by rapid technological progress. Therefore, there is only a weak justification for expecting an effect of market structure (in the Schumpeterian sense) on innovative productivity.

There are two other arguments which suggest that the structure of an industry may influence the innovative productivity of firms in it. These arguments are, however, distinct from the Schumpeterian effects and in fact provide predictions that are at odds with the Schumpeterian logic. The first of these stems from the nature of the innovative process, while the second draws upon a broader conception of industry structure than has been used in the industrial organization literature. Both arguments draw upon a common notion of knowledge spillovers.

Descriptions of the process of innovation stress the role of uncertainty and serendipity (Kamien & Schwartz, 1982; Nelson & Winter, 1982). Often, only a few of many ongoing lines of research yield productive results. Many result in no useful output. Usually it is not possible to identify, *a priori*, which line of effort is likely to be productive (Henderson & Cockburn, 1994; Nelson & Winter, 1982). If research efforts are imperfectly correlated across firms, in the sense that the success or failure of one research effort does not imply the success or failure of another effort, then research efforts by several firms improve the possibility that at least some efforts are successful (Dasgupta & Maskin, 1986; Nelson, 1959) Successful efforts may in turn provide information on more productive research trajectories (Dosi, 1982, 1988; Henderson & Cockburn, 1994; Malerba, 1985; Nelson & Winter, 1982), and help to improve innovation performance even in firms whose initial efforts were not successful. Hence, the presence of imperfectly correlated research efforts by several firms can influence research productivity (Kamien, Muller, & Zang, 1992). To the extent that oligopolistic market structures may result in fewer uncorrelated research efforts, market structure may have an impact on the innovative productivity of all the firms in the industry (Dasgupta & Maskin, 1986; Merges & Nelson, 1994). This argument thus provides a rationale for market structure as an argument to the innovation production function.

The second argument builds on a much broader notion of industry structure than is implied by the conventional concentration measures. Industries, especially technologically focused industries, are increasingly being marked by the formation of many inter-firm alliance relationships between firms (Hagedoorn & Schakenraad, 1990). These relationships and the resultant networks have been described as "hidden industrial structures" (Hakansson, Kjellberg, & Lundgren, 1993). Since these networks are composed of links formed for the explicit purpose of sharing resources and knowledge, it is plausible that they help in the transmission and diffusion of knowledge within the industry. If networks serve as information conduits, then the structure of the network in a given industry can influence the innovative productivity of firms in that industry (Ahuja, 2000a). Industries characterized by well-connected networks may lead to increased knowledge spillovers which aid innovative productivity in those industries relative to industries with less-well-connected networks. In a variation on this argument, one could argue that industry networks that are very cohesive may lead to greater homogeneity of research approaches. In contrast, networks characterized by a small world or disjointed clique structure may generate more variegated research efforts. Although at the firm and inventor level such explorations have begun (Schilling & Phelps, 2007), no study directly examines the effect of differing network structures across industries.

Summary. In conclusion, market structure in the Schumpeterian sense, cannot be strongly linked to innovative productivity. Nevertheless, market structure may still be an argument to the innovation production function on account of two other effects: (a) the number of independent research efforts promoted under different market structures may differ and thus may lead to different rates of technical progress; and (b) the presence of a substructure of inter-firm linkages may act as an information channel providing speedy access to knowledge spillovers. Industries that are marked by poorly connected substructures may convey information less efficiently than industries marked by more efficiently connected substructures, leading to differences in the rates of technical advance. However, relatively little economics work has addressed these two latter interpretations of market structure, and this constitutes another opportunity for further research. In the paragraphs that follow, we examine the burgeoning management literature that has looked at the relation between networks and innovation (Ahuja, 2000a; Arora & Gambardella, 1994a; Baba & Imai, 1993; Barley, Freeman, & Hybels, 1992; Ciborra, 1992; Della Valle & Gambardella, 1993; Freeman, 1991; Jane Bower, 1993; Lee, 2007; Owen-Smith & Powell, 2004; Powell & Brantley, 1992; Saxenian, 1991; Shan, Walker, & Kogut, 1994; Storper & Harrison, 1991). The central propositions of this literature suggest both a direct and an indirect impact of networks on innovation productivity.

1.2 Collaboration Networks

Introduction. As argued in the previous section, the substructure of inter-firm relationships within an industry, by being a conduit of information and ideas, can impact the innovativeness of firms leading to a vibrant management literature in the area (see section 3.3 below). The impact of inter-firm collaboration networks on firm innovativeness has been studied at various levels. Scholars have studied the role of inter-firm alliances (Arora & Gambardella, 1990; Lane & Lubatkin, 1998; Shan et al., 1994) in a dyadic fashion, the role of a firm's position in the network resulting from such dyadic alliances (Ahuja, 2000a), and less commonly, the impact of the structural features of inter-firm relationship networks as a whole. In this section, we concentrate on the last group of studies, leaving the first two for the section on firm-level characteristics.

Networks and the research production function. Some theoretical clarification is probably an important precondition to understanding the findings in the literature on networks and innovation. The first issue to understand in this context is why the network should at all be regarded as an appropriate level of analysis as distinct from an individual firm. Two broad arguments suggest why the network construct might be useful in the context of innovation. The first argument draws from the division of labor reasoning that has been suggested by both economists (Arora & Gambardella, 1990, 2008) and sociologists and organization theorists (Powell, Koput, & SmithDoerr, 1996). According to this argument, in many industries the task of innovation has been sub-divided among a number of interconnected firms such that the appropriate locus of innovation is now this network or clique of interconnected firms, rather than the individual firm. Understanding innovation may thus require the study of such cliques rather than standalone firms. A second argument that suggests that the network could be a useful construct in the study of innovation draws upon the idea that while all inter-firm networks are ultimately composed of individual inter-firm linkages (and hence all advantages of cooperation that are valid for a dyadic linkage remain valid for a network composed of many such linkages), there are nevertheless distinctive effects that arise additionally from the network as a collective entity. This second argument, which draws upon sociological antecedents, thus suggests that the network of ties that results from the aggregation of individual inter-firm ties has economic content of its own, beyond those of the ties that compose it. This content consists of some flow such as information or advice or trust that flows through these network ties to the firms that constitute the network (see the next section for one detailed representation of how this might occur). From this perspective, networks can be seen as both pipes through which information flows or prisms through which information is selectively amplified and transmitted (Podolny, 2001; Soh, Mahmood, & Mitchell, 2004). Thus, networks represent a social overlay for an industry that has cognitive and informational implications.

Most of the attention of management scholars has been focused towards understanding the impact of network structure on the productivity of innovation. The impact of network structure on the motivations to invest in innovation has received relatively less attention. However, some arguments suggest that the structure of inter-firm networks in which they are embedded affects firms' motivations to invest in innovation as well. First, inter-firm networks are a good source of information about opportunities and threats that exist in the market (Uzzi, 1997; Zaheer & Bell, 2005). A proper understanding of the market conditions increases the probability that firms can create innovations that serve market demands and therefore profit from innovations (Christensen & Bower, 1996; Schmookler, 1966). Networks, therefore, can spur firms to invest in innovation by increasing their probability of profiting from innovation. Relatedly, in their role as prisms, networks can amplify or weaken the signals provided by the market (Soh et al., 2004). Economists have argued that signals that reduce the uncertainty of returns from investments in R&D are important to encourage investment in R&D. Soh et al. (2004) demonstrate that the network of firms can be an important mechanism for reducing such uncertainty by showing that external endorsements such as new product awards that can reduce the uncertainty of the returns to R&D investments are more valuable for players with limited access to the network than for well connected players. Consequently, the R&D investments of peripheral players are more sensitive to signals such as awards.

Networks can also lead to the diffusion of practices through imitation (Davis, 1991; Westphal, Seidel, & Stewart, 2001). Institutional scholars (Davis, 1991) and organization theorists (Westphal et al., 2001) have found that not only do firms imitate innovative decisions (Davis, 1991) but also the processes of making decisions (Westphal et al., 2001). This tendency increases under conditions of uncertainty (Dimaggio & Powell, 1983). Under uncertain conditions, some of the firms may resort to changing—either expanding or reducing—investments in innovation. This decision to expand (or contract) research expenditures may be imitated throughout the network affecting the overall rate and direction of innovation in the network beyond what one would expect from purely economic calculus (DiMaggio & Powell, 1983; Davis, 1991; Westphal et al., 2001).

Networks and the innovation production function. Inter-organization networks promote innovation productivity directly by providing information and technical knowhow and facilitating joint problem solving (Debresson & Amesse, 1991; Freeman, 1991; Midgley, Morrison, & Roberts, 1992; Saxenian, 1991). Given a technological environment requiring competencies and knowledge of multiple technology bases, it is increasingly difficult for even the largest firms to keep abreast of knowledge in all relevant fields (Ciborra, 1992). Further, the need to develop systemic solutions for customers suggests that this differentiation in knowledge generation across firms must be combined with integration in knowledge application between them (Demsetz, 1991; Grant, 1996). Networks present a low-cost and flexible alternative to achieving this (Ciborra, 1992). Indeed, this argument has been extended to suggest that in many technologies, with the supply of knowledge increasingly distributed across firms, the appropriate locus for innovation in many contemporary technologies is the network of firms, and not individual firms (Arora & Gambardella, 1990, 1994b; Powell et al., 1996).

Networks also promote innovation productivity indirectly by facilitating increased specialization and division of labor, which leads to more focused expertise development (Piore & Sabel, 1984; Saxenian, 1991). This specialization is made possible by the reduction of transaction costs occurring through increased levels of trust between the transacting parties (Arrow, 1974; Bradach & Eccles, 1989; Dodgson, 1993; Jarillo, 1988). Networks are critical to this development of trust for at least two reasons. First, they represent arenas of repeated interaction between the same parties. Hence, reputation effects are operative through a "shadow of the future": opportunistic behavior by one party will engender similar behavior by the other party in subsequent interactions leaving both worse off, thus providing an incentive to both parties to behave appropriately (Axelrod, 1984; Deeds & Hill, 1999; Gulati, 1993; Heide & Miner, 1992; Hill, 1990; Kogut, 1989; Kreps, 1990; Parkhe, 1993). Second, the network is an information conduit linking not just the players currently engaged in a linkage, but many other players who are on other nodes of the same network. Opportunistic behavior is thus known not just by the affected party but also by many others. Therefore, opportunistic actions have behavioral consequences not just with respect to immediate partners but also with respect to many *potential* partners (Burt & Knez, 1995).

Future directions. The above arguments are compelling, and establish a case for studying the sociological effects of alliance structures in industries. However, in spite of this general recognition, initial tests of the hypotheses embedded in the above propositions, and formal analyses of networks in the context of innovation, are limited (Debresson & Amesse, 1991). More recent research has attempted to correct the limitations of the initial phase by testing the main propositions in large sample studies and employing formal structural arguments. Even so, many questions still remain unanswered. Understanding the conditions under which the network structures that support innovation in a given industry look different from network structures in other industries remains open to question. Further, it is not clear that we have a good theory yet that predicts the conditions under which we should expect to see a distribution of innovative labor of one type versus alternate patterns of knowledge specialization. Equally, the mechanisms through which networks influence the innovation process need to be illuminated. Although research on networks of alliance ties has established that network position of individual firms matters for innovation output, thus suggesting that this characterization of networks as conduits for the flow of technical information in an industry is meaningful, the actual comparison of industries with different network structures that has led to differential rates of innovation still remains open for further investigation.

Another major issue to keep in mind, which the voluminous literature on networks and innovation has regrettably not always done, is to make a distinction between the different types of inter-firm networks. At the very minimum, two broad classes of networks can be distinguished. On the one hand, networks can be horizontal; composed of ties between competitors. Alternately, networks can be vertical; composed of ties between firms and their buyers, suppliers or complementors. A network among firms in the chemicals industry would be an illustration of a horizontal network, while keiretsu ties would be one illustration of a vertical network. Whether it is information, trust or advice that is flowing through networks, it is likely that whether the networks are vertical or horizontal matters. Horizontal networks represent a collaborative counterpoint to the normal pursuit of competition by firms in an industry. Presumably, a network effect here would mean that deeply embedding a given competitive tie within the broader industry network (i.e. becoming central in the industry network) leads to a suppression of intensely competitive behavior. Vertical networks on the other hand are meaningful (potentially) because they represent a "thickening" of the buyer–supplier ties relative to the market interface which is the normal domain of these relationships. Understanding how the softening of competition or the thickening of buyer–supplier ties influences innovation still needs to be clarified (though see the section on firm positions in networks later).

1.3 Buyer/User Innovation

Introduction. Most of the research on innovation discussed so far has two underlying premises: one, firms are the originators of innovation; and two, innovators are driven to innovate by the profit motive. Neither of these premises has gone unchallenged. Researchers have also identified users as a major source of innovation. Further, the users have been argued to be motivated by considerations other than profiting directly from the innovations (Jeppesen & Frederiksen, 2006; von Hippel, 1976, 1986). These researchers, therefore, not only point towards a new source of innovations but also indicate alternative motivations for innovation activities.

Researchers such as von Hippel (1988) and his colleagues show that users have made significant contributions to innovations in industries ranging from those in the industrial sector such as petroleum and chemicals to high-tech sectors such as semiconductors to consumer products. While the economic effects of user innovation have not received much attention by researchers (Jeppesen & Frederiksen, 2006), such innovations can be of great value to the firms for a number of reasons. First, they serve as a source of marketing data for the firms—with the help of lead users, the firms can gauge the future trends in the industry. Second, the user innovations may be a source of valuable product ideas which can enable the firms to either launch new products or significantly improve their existing product performance. Realizing this potential, some firms help the users to innovate by providing them "open systems" (Garud & Kumaraswamy, 1993) or setting up user groups (Jeppesen & Frederiksen, 2006).

Given the importance of user innovations, researchers in this stream have paid a lot of attention to identifying the factors that encourage buyers to innovate and thus have identified new arguments to the research production function. Research on factors that impact the productivity of user's innovation efforts is, however, relatively sparse. In this section, therefore, we concentrate on the factors that motivate users to innovate.

Buyer innovation and the research production function. Research on user innovation has identified several factors that motivate the users to innovate, which can be broadly classified into three categories. First, the users have certain inherent characteristics—whether they are hobbyists or lead users—that motivate them to innovate. Second, the users may gain psychological benefits from the recognition given by the firm that motivates them to innovate. Third, the users are motivated because of reputation and signaling benefits which help them on the job market (Lerner & Tirole, 2002).

One characteristic of users that are motivated to innovate, especially in the consumer goods context, is that they are hobbyists (Franke & Shah, 2003; Jeppesen & Frederiksen, 2006; Luthje, Herstatt, & von Hippel, 2005; Shah, 2000), i.e. people who innovate in areas that are different from the area of their primary occupation (Jeppesen & Frederiksen, 2006). These innovators typically reveal their innovative ideas free of charge in user communities, some of which are hosted by firms themselves. Thus, such users don't seem to be driven by monetary rewards. Rather, they seem intrinsically motivated. Theories from social psychology (Deci, 1975) and behavioral economics (Benabou & Tirole, 2003) suggest that extrinsic motivation devices such as performance based rewards crowd out intrinsic motivations. In contrast, rewards that are "non-controlling" (Jeppesen & Frederiksen, 2006) such as encouragement etc., enhance intrinsic motivation. In a classic experiment (Deci, 1975; Jeppesen & Frederiksen, 2006), it was noted that students who were not paid to work on an interesting problem continued to work longer in their leisure time than the students who were paid to work on the problem. The "crowding out" theories thus provide one reason why hobbyists are more likely to contribute freely to innovation than professionals. Other psychological theories (Eisenberger, Pierce, & Cameron, 1999), however, present a more nuanced view of the "crowding out" perspective; the effect of extrinsic rewards on intrinsic motivation may be contingent on many factors such as how the award is presented.[2] This suggests that firms, by carefully choosing awards, can, in fact, increase user innovation. This identifies a great avenue for future research.

Another major category of users who contribute significantly to innovation are the "Lead users" (Jeppesen & Frederiksen, 2006; Morrison, Roberts, & Midgley, 2004; von Hippel, 1986). Following von Hippel (1986), Jeppesen and Frederiksen (2006, p. 51) define lead users as users who have two characteristics— "a) they expect innovation-related benefits from a solution and are thereby motivated to innovate; and b) they experience the need for a given innovation earlier than the majority of a target market". Clearly, the first characteristic of the lead users makes them want the innovation more than other users by definition. But why do they innovate themselves rather than waiting for the firm that supplies them? The second criterion in the definition provides the answer. Another way of stating the second criterion is that the need for innovation felt by lead users is not yet shared by the majority of users. Hence, the size of the market for innovation may not be large enough for the firm to invest in the innovation. In these circumstances, the lead users may take it upon themselves to innovate making them more likely to innovate than other users. Obviously, this likelihood will be moderated both by the level of technological capability of the lead user and the amount of slack in terms of time and money possessed by the lead user (Morrison, Roberts, & von Hippel, 2000).

Another non-monetary motivation for users to innovate, especially in the context of firm-hosted user communities is the recognition provided by the firms to the innovations and the innovators (Jeppesen & Frederiksen, 2006). Users may innovate and contribute their innovations freely in firm-hosted user communities (typically online) in order to be recognized by the firm. Users gain psychological benefits such as sense of pride among other users or gratification on being recognized for their efforts (Jeppesen & Frederiksen, 2006). This non-monetary mechanism to motivate users to contribute their innovations needs much more theoretical and empirical attention in the literature.

Another reputation-based mechanism that motivates users to contribute their innovations freely which is probably more prominent than the firm-recognition hypothesis is that users contribute freely in order to gain reputation among peers and to signal their competence in the job market (Lerner & Tirole, 2002). According to this theory, users contribute innovative efforts to gain reputation capital which they may use in later job searches. This mechanism may be especially relevant in circumstances where a user's contribution is visible among the peers and in the job market such as in the open source environments. However, this explanation would predict that professionals are more likely to contribute innovations than hobbyists since professionals are most likely to gain from sending positive signals to the job market. This explanation thus conflicts with the intrinsic motivation explanation discussed earlier. Ambiguities and conflicts such as this suggest the need for greater exploration of contingency arguments by researchers in the user innovation area.

1.4 The Role of Suppliers and Complementors

Introduction. Most of the studies examining motivations to innovate have looked at how conditions within an industry—competition, concentration, appropriability conditions and technological opportunities—affect the incentives to exert innovation efforts. The role of technological spillovers across industries in providing incentives to innovate has received relatively less attention. However, inter-industry knowledge spillovers are an important source of innovation in many industries (Vanderwerf, 1992) and may provide strategic motives to invest in innovation (Harhoff, 1996). In this section, we explore how knowledge spillovers between suppliers, buyers and complementors may affect the incentives to innovate. Research on how inter-industry dynamics may affect the productivity of research efforts is even scarcer. Scholars studying inter-firm alliances, however, do argue for alliances between partners to provide complementarity benefits (Arora & Gambardella, 1990; Gans, Hsu, & Stern, 2002), a line of research we shall explore in detail in the section on inter-firm alliances. In this section, therefore, we concentrate on the role played by inter-industry dynamics on the incentives to innovate: the research production function.

The suppliers, complementors and the research production function. There are two reasons why suppliers of an industry may be motivated to invest in innovations and increase the technological opportunities in the downstream industry. First, conditions in the downstream industry may induce lesser innovation effort than is optimal from the supplier's perspective (Harhoff, 1996). For instance, differences in the economic conditions—concentration, appropriability—between the supplier and the downstream industry may render the innovative efforts by the downstream firms inadequate to take advantage of the greater pace of innovations in the supplier's industry. In such circumstances, the supplier may be motivated to augment the downstream industry's research by investing in R&D activities (Harhoff, 1996) that improve the quality of final goods or better utilize upstream innovations. This motivation may, in part, be driven by faster technological growth in the supplier industry than the downstream industry coupled by innovation disfavoring conditions in the downstream industry.

Another reason for suppliers to invest in downstream industries may emerge if downstream industry is concentrated and has significant barriers to entry such as sunk costs in some component of the industry's value chain. In such a context the supplier has strong incentives to reduce those sunk costs by investing in R&D activity in the downstream industry. Reduction in such sunk costs should lower entry barriers and foster competition for the current buyers (Harhoff, 1996). Symmetric arguments apply for the firms in the downstream industry to invest in innovative activity upstream.

In addition to buyers and suppliers, complementors also have an interest in the development of technology (Afuah, 2000; Ethiraj, 2007). Although research in the strategy area has broadly examined the issue of complementarity, a significant focus of the research has been on the relative merits and demerits of ownership of complementary assets by incumbents or the strategies of firms to obtain access to complementary assets (Rothaermel, 2001; Tripsas, 1997). Far less research has examined how complementors to a given industry may be relevant to understanding the rate of technical progress in the industry. The returns from investments that complementors make in their own technologies often depend significantly on the availability and performance of complementary technologies, especially in systems products. In an innovative paper, Ethiraj (2007) uses the context of the PC industry to show that the allocation of a firm's inventive effort was significantly influenced in the direction of those components of the PC that were complements of the firm's technology but were constraining system performance, even if the focal firm was not in the business of manufacturing or selling that particular component. In general though, the complementors role in innovation has been under-researched, as indeed is true more broadly of the role of suppliers. For instance, under what conditions, beyond the one mentioned above, one would expect to see complementors engaging in research efforts in the focal industry is still unclear. Further, how the presence or absence of complementors' research efforts affects the productivity of conducted research is also not addressed. Investigating the role of suppliers and complementors in innovation is clearly an important under-researched issue.

Future directions. The above discussion suggests that while studying the impact of industry characteristics on motivations to innovate, researchers should not limit themselves to examining the conditions of the focal industry alone. It is also crucial to consider the inter-industry dynamics, both economic and technological, as well. Further, taking such dynamics into account also identifies several new factors that may influence a firm's decision to invest in innovation both in its own industry as well as in industries either upstream or downstream or complementary to the focal industry.

1.5 Innovation and Industry Effects: A Summary

The above discussion highlights the importance of separating the question of firm innovativeness into two questions: (1) what factors influence the incentives to exert efforts in innovation? and (2) what determines the productivity of those efforts? As was pointed out earlier, the inconclusiveness of empirical research relating industry structure to innovation may partly be due to the inadequate attention paid to how the industry structure influences the productivity of innovation efforts. A clearer conceptual separation of the two stages of the innovation process may lead researchers to bring new insights into understanding the industry structure—innovation relation. Further, most of the research discussed in this section, with perhaps the exception of the role of networks, has concentrated largely on the incentives of innovative efforts. Since the increases in innovativeness also require increases in the productivity of inventive efforts, a systematic exploration of how the structure of the industry affects the productivity of innovative effort will lead to a more complete understanding of the impact of industry on firm innovativeness.

The management research adds significantly to our understanding about the impact of industry structure on innovativeness of firms. It identifies new elements of the industry structure that can have significant impact on innovations.

Industries with similar concentration and size distribution of firms may have a different substructure of inter-firm relationships, different norms amongst the user community, varying degrees of support to user innovators, users of differing capabilities and different patterns of technological growth *vis-à-vis* upstream, downstream and complementary industries. Exploring the interactions between these determinants, for example, examining how the substructure of inter-firm relationships interacts with the efficacy of user innovation, may lead to interesting new avenues of research.

2. Firm Characteristics and Innovation

Identifying what kind of size distribution of firms is most conducive for innovation has been a key part of the Schumpeterian legacy. However, we argue here that many characteristics beyond firm size are relevant to understanding innovation outcomes. To cover this terrain, we will begin with the Schumpeterian arguments but note that a detailed consideration of those leads to consideration of these many other influences. In this manner we try to bring together the voluminous management literature on these other characteristics with the economics literature on firm size. As before, we retain our innovation production function and research production function framing to structure the literature. We begin by addressing the issue of firm size.

2.1 Firm Size

Introduction. Empirical results of the simplistic interpretation of the relationship between firm size and firm innovativeness are inconclusive (Cohen, 1995). In this section, we shall examine the various reasons why firm size should influence a firm's innovative output and explore the reasons behind the inconsistency of results. Exploring the reasons of inconclusiveness not only leads us to a more nuanced understanding of the size–innovation relationship but also helps to identify other attributes of firms such as firm scope and its network of alliances as possible determinants of firm innovativeness. As before, we begin by distinguishing between effects of firm size on innovative efforts and its effects on the productivity of those efforts.

Size as an argument to the research and innovation production functions. The validity of size as an argument to the innovation production function is confirmed by the existence of at least two positive and two negative influences of size on innovative productivity (Cohen & Levin, 1989; Galbraith, 1952; Schumpeter, 1942): (a) scale economies in the R&D process benefit firms with larger R&D budgets; (b) R&D is more productive in large firms due to complementarities between R&D and other activities; (c) bureaucratization of inventive activity in large firms stifles the creative instincts of researchers; and (d) in large firms, incentives of individual scientists become attenuated as their ability to capture the benefits of their efforts diminishes. Given the possibility of these four effects, size is clearly a valid argument to the innovation production function. Size also affects innovative effort through at least two means: (a) large firms can secure finance for risky R&D projects; and (b) returns to R&D are higher if the innovator has a large volume of sales over which to spread the fixed costs of innovation. Hence, it is a valid argument to the research production function too.

The above list of influences shows that size has both positive (a, b) and negative (c, d) effects on innovative productivity. Therefore, *a priori*, it is not clear that the Schumpeterian thesis of a positive impact of size on innovation should unambiguously hold if our variable of interest is innovation *output*. This difference between the effects of size on innovative effort (unambiguously positive), with its effects on innovative output (both positive and negative), is consistent with Scherer's conclusions from a review of the empirical evidence on the size–innovation relationship (Scherer, 1984): "…size is conducive to vigorous conduct of R&D,… By every measure used, the group of large corporations as a whole contributed fewer significant innovations, contest-wining technical advances, and innovation patents per million dollars of R&D than smaller enterprises" (pp. 234–237).

An even more interesting aspect of the two positive influences of size is that large size by itself is neither *necessary* nor *sufficient* to realize the above positive effects. Large size is not *necessary* to realize the benefits of scale and complementarity as, at least in theory, two firms that collaborate in innovative activity can achieve both these objectives without either being large. Large size is not *sufficient* to realize these benefits because even if the firm is large but there are no increasing returns to scale in the R&D activity, large size will present no scale advantage relative to smaller sized firms. Similarly, even if a firm is large but is functionally specialized and therefore conducts only one activity, no benefits of complementarity in the sense of (b) will accrue.

This discussion clearly indicates that the relationship between size and innovative output is far more complex than is envisaged by the Schumpeterian hypothesis. Further, it implies that any attempt to estimate this relationship must control for the influence of some of the contingencies identified above. To the extent that past research has failed to do so, its inconclusiveness is not surprising. Going further, we elaborate on two such contingencies which are of relevance in any estimation of the role of size in the innovation production function.

The first contingency this discussion establishes is that a distinction must be made between the size of the firm, the size of the R&D effort, and the scope of the firm's activities. All of these represent conceptually distinct effects. The size of the firm is an indicator of the bureaucratic and incentive structure of the firm, and by itself might imply only a negative effect on innovative productivity for the reasons discussed earlier. The size of the R&D effort reflects the actual inputs to the innovation task. Unless R&D is subject to strongly diminishing returns, within a broad range of values the effect of R&D should be unambiguously positive on innovation output. Finally, a firm's scope reflects the availability of complementary resources *within* the firm. If these are not available then even large firms may lack the advantages attributed to complementarities.

The second contingency this analysis establishes is the need to examine relationships between firms as a valid argument to the innovation production function. The scale and complementarity benefits discussed above could be obtained through cooperation between firms, rather than necessarily from within a single firm (Doz, 1987; Horwitch & Thietart, 1987; Olleros & Macdonald, 1988; Teece, 1986). Further, inter-firm cooperation could mitigate the problems of bureaucratization and incentives (Doz, 1987; Rothwell, 1991; Rothwell & Dodgson, 1991). Hence, for both these reasons, if there exist relationships between firms, studying them is necessary to understand the factors determining the productivity of research efforts. This argument provides further support for our decision to consider not just the competitive effects of a given distribution of firms in an industry but also the collaborative effects of such firms.

Empirical results. Empirical research on the issues of size and innovation has closely paralleled the conceptual logic described above. Early, relatively naïve, views of the role of size have been replaced by progressively more sophisticated awareness of the complexity of these effects, culminating in the consensus that both large and small firms are critical and complementary to the process of innovation, and studying the relationships between firms is likely to yield significant insights into the process of innovation (Cohen & Levin, 1989). For the purposes of this review we separate the research effort into three distinct phases. Studies in the first phase are distinguished by a focus on testing the Schumpeterian hypotheses in their simplest form by looking for correlations between size and innovation, and market structure and innovation. The second stage of the effort is marked by examination of more sophisticated versions of the Schumpeterian hypotheses through inclusion of other variables of interest. The third phase of the research effort is marked by a move away from literal interpretations of Schumpeter in an attempt to identify more fundamental determinants of innovation (Cohen & Levin, 1989). It is in this last phase that the relationships between firms have become the focus of research.

Early efforts focused on testing the Schumpeterian hypotheses in their simplest form, without regard for many of the contingencies discussed in the previous section. Measures of innovative output and input were regressed against measures of size and market structure in attempts to validate Schumpeter's "impressionistic empiricism", with only limited regard for the conceptual foundations of those effects (Baldwin & Scott, 1987). A failure to distinguish between innovative inputs and innovative outputs, use of naïve models, and lack of controls for firm and industry differences in factors such as technological opportunity, ensured that results from this stream of research were in general inconclusive (Cohen & Levin, 1989). Given the complexity of the relationship between market structure, size and innovative output discussed above, and the simplistic view of the process embodied in this research stream, this result is, in retrospect, unsurprising (Baldwin & Scott, 1987; Cohen & Levin, 1989; Kamien & Schwartz, 1975, 1982; Scherer & Ross, 1990).

Later analyses of innovative productivity have adopted progressively more sophisticated conceptual and methodological approaches (Cohen & Levin, 1989; Hausman, Hall, & Griliches, 1984). Conceptually, many of the arguments and distinctions discussed above have been operationalized. Notable among the variables included in more recent studies are *firm size* (Comanor, 1964; Graves & Langowitz, 1993; Henderson & Cockburn, 1996; Jensen, 1987; Kamien & Schwartz, 1982, pp. 82–84; Scherer, 1965; Schwartzman, 1976; Vernon & Gusen, 1974), *size of research effort* (Comanor, 1964; Graves & Langowitz, 1993; Henderson & Cockburn, 1996; Jensen, 1987; Scherer, 1965; Schwartzman, 1976; Vernon & Gusen, 1974), *scope* of the research activities of the firm (Henderson & Cockburn, 1996), and *internal organization* of R&D effort (Henderson & Cockburn, 1994). Methodologically, newer techniques and richer data and measures have been brought to bear on these questions (Acs & Audretsch, 1987; Chakrabarti, 1991; Halperin & Chakrabarti, 1987; Hausman et al., 1984; Henderson & Cockburn, 1994, 1996; Lieberman, 1987).

Three features of this second phase of the research effort bear special comment. First, these conceptual and methodological improvements have occurred in a piecemeal fashion, and there are no studies in the Schumpeterian tradition which examine the issue of innovative productivity in a comprehensive fashion. Some studies ignore issues of complementarity, while others fail to distinguish between the determinants of innovative effort and innovative output leading to difficulty in the interpretation of their results. Second, almost all, including the most comprehensive and detailed of these studies, ignore the role of inter-firm cooperation in the process of innovation despite the logic that deficiencies and advantages of size can possibly be made up or leveraged through suitable collaborative strategies. Third, in spite of superior formulation and implementation of models, results continue to be inconsistent. Some studies find a positive effect of firm size and research effort on innovative productivity (Lieberman,1987; Schwartzman, 1976), others find negative or no effects of both (Chakrabarti, 1991; Graves & Langowitz, 1993; Halperin & Chakrabarti,1987), and some find positive effects of one variable but negative effects of the other (Comanor 1964; Vernon & Gusen 1974). Still others find these results moderated by the industry's degree of concentration (Acs & Audretsch, 1987, 1988; Dorfman, 1987; Lieberman, 1987).

Summary. These enduring inconsistencies in empirical tests of the Schumpeterian propositions have prompted widespread recognition of the subtlety and interplay between size and firm characteristics in the process of innovation (Baldwin & Scott, 1987; Cohen & Levin, 1989). Attention to the role of complementarities between firms in generating innovations was first drawn by Jewkes, Sawers, and Stillerman (1969) who argued that innovations were realized through the interactions of firms that are distinguished by size, expertise and other attributes, rather than by any single type of "innovative" firm. As they conjectured in the conclusion of their book, *The Sources of Invention*, "It may well be that there is no optimum size of firm but merely an optimal pattern for any industry, such a distribution of firms by size, character, and outlook as to guarantee the most effective gathering together and commercially perfecting of the flow of new ideas" (Jewkes et al., 1969, p.168). This need to study the role of firm–firm, and firm–institution complementarities and relationships was recognized by some scholars (Nelson, 1986), but was long under-emphasized. Only over the last two decades has there emerged a consensus of the need to study such complementarities (Baldwin & Scott 1987; Cohen & Levin, 1989). Consideration of these complementarities naturally leads to enumeration of the different ways such complementarities can be obtained by the firm. The most obvious mechanisms would be through an expansion of the scope of the firm or by obtaining access to such complementarities through relationships with other firms. We address these two mechanisms next.

2.2 Firm Scope

Introduction. As discussed in the previous section, a prominent factor through which size is argued to influence innovation—complementarity benefits—may actually operate through firm scope. In this section, we discuss the various mechanisms through which firm scope is argued to influence both innovation efforts and the productivity of those efforts. In doing so, we also explore the conceptual and empirical problems with the mechanisms.

The positive influence of firm scope on innovation. The role of firm's diversification in providing motivations to invest in research was first argued by Nelson (1959). His primary argument, the "diversification" hypothesis, was that firms with a broad product base have greater incentives to invest in basic research. This is because of two features of research in basic science. First, it is difficult to predict how and where one can apply the knowledge resulting from research in basic science; research done in one area may yield knowledge that is more applicable to other areas. Second, basic research is more likely to yield knowledge which can be applied to multiple domains. These two factors mean that firms with a broad product base are more likely to benefit from the fruits of basic research and are, therefore, most likely to invest in research activities.

The "diversification" hypothesis applies more to basic research than to applied research (Link, 1982; McEachern & Romeo, 1978), which is more narrow in scope. In a cross sectional study of 275 US manufacturing firms, Link (1982) found diversification to be a significant predictor of investments in basic research but not in applied research. However, most of the research activity in the industrial sector is development and applied research (McEachern & Romeo, 1978). Given this characteristic, the knowledge generated by R&D in firms may apply only to a closely related set of businesses a firm is engaged in (McEachern & Romeo, 1978). This suggests a modification to the "diversification" hypothesis: it is related diversification, and not overall diversification, that positively influences investments into R&D. This modified version was empirically verified by McEachern and Romeo (1978).

Another mechanism through which diversification promotes innovation is provided by Chen (1996). He proposed that firms actively engaged in diversification followed prospector strategies and were more sensitive to new opportunities. Thus, apart from the static scope of a firm, the active pursuit of diversification strategy indicated a mindset of exploration and therefore led to greater R&D activities.

Diversification can also influence innovation productivity by facilitating cross pollination of ideas across domains. Knowledge transfer maybe easier inside organizational boundaries compared to inter-firm knowledge transfer (Miller, Fern, & Cardinal, 2007; Teece, 1982) because of shared organizational codes and language (Grant, 1996) and reduced threat of opportunism (Williamson, 1975). Miller et al. (2007), for instance, found that innovations that result from interdivisional knowledge transfer impact future innovations more than those that are result by sourcing knowledge from outside the firm or those that are created by knowledge within a single division.

The negative influence of firm scope on innovation. The positive influence of breadth on innovations has been challenged by economists and management scholars alike who argue that diversified firms may find it difficult to implement incentive structures that motivate their managers to invest in risky activities. Rotemberg and Saloner (1994), for example, argue that in a firm with broad related product lines, inventions from one division may not be implemented because of substitute inventions from a related division. Under information asymmetry, firms compensate employees or innovation efforts only when their inventions are implemented. The threat of substitute inventions in diversified firms reduces the chances of implementing an invention and consequently the chances of compensating the employee for innovation efforts. This reduces the incentives to exert efforts for the employee.

Another challenge to the "diversification" hypothesis has been posed by scholars researching strategy implementation (Baysinger & Hoskisson, 1989; Hoskisson & Hitt, 1988). These scholars suggest that as a firm becomes more diversified, the top management at the corporate level has greater difficulty in monitoring individual divisions (Hoskisson, Hitt, & Hill, 1991). This is because increased diversification creates information overload. Besides, the more diversified a firm, the greater is the likelihood that the businesses are beyond the competence of corporate managers (Hoskisson et al., 1991). This "control loss" leads firms to move from strategic control, i.e. subjective evaluation of performance based on strategic decisions taken by mangers, to financial controls, i.e. evaluation of performance based on meeting objective financial targets such as return on investment. This change in control systems makes the division managers more shortsighted and risk-averse. The managers use the information asymmetry to negotiate lower financial targets. They focus their attention on achieving short-term financial targets, thereby reducing expenditures to research with a long-term focus. These scholars (Baysinger & Hoskisson, 1989; Hoskisson & Hitt, 1988) predict and test the hypothesis that diversification in general, and unrelated diversification in particular, reduce R&D intensity.

The challenges to the basic "diversification" hypothesis that are discussed above also raise questions. The basic argument that financial controls make the managers risk-averse and therefore adversely impact innovation (Baysinger & Hoskisson, 1989; Hoskisson & Hitt, 1988) presumes that divisional managers are punished for not meeting financial goals but ignores the possibility that divisional managers may be rewarded for spectacularly exceeding the goals. This lure may serve as an incentive to invest in research efforts. Further, the argument ignores the possibility that in certain industries, not investing in research may pose greater risks than investing in research and that in such industries it is likely that the compensation contracts of managers may account for such possibilities. Finally, single business firms that are public are also primarily evaluated by the financial markets on objective financial criteria such as return on investment. So, heads of single business firms should display the same risk-aversion that is displayed by division-heads in widely diversified firms. Diversified firms, to the extent that they have the option of substituting strategic controls for financial controls, may in fact encourage risk-taking compared to single-business public firms. Hence, diversified firms should at least provide the same incentives for risk-taking as single-business firms.

Hoskisson et al. (1991), following the above line of logic, suggested that diversification may have an inverted U-shaped relationship with risk-taking: intermediate levels of diversification may be better than no or too-much diversification. However, this inverted "U" relationship has not been subject to extensive testing. McEachern and Romeo (1978) proposed and tested another reason why unrelated diversification may predict reduced R&D intensity. They propose that when firms whose primary business is in high R&D intensity areas diversify, they may move to areas which need less R&D and thus on average, are observed to have lower R&D intensities. In a study of 40 firms in drugs, chemicals and petroleum refining, they found that the R&D intensity of firms that were primarily in drugs and chemicals (high R&D intensity industries) was negatively impacted by unrelated diversification when compared to firms that were primarily in petroleum refining (a lower R&D intensity area). On the other hand, Baysinger and Hoskisson (1989) do not find any effect of the interaction of technology opportunity with the kind of diversification in their study. Regardless, the above studies show the importance of controlling for industry effects. However, as scholars (Hoskisson & Hitt, 1988) in this tradition have pointed out, the industry controls in many such studies may not be adequate since usually only the primary industry is controlled for although it may represent a small proportion of a firm's overall portfolio.

In a study that is also one of the relatively few international studies in the area, Mahmood and Mitchell (2004) examine a variant of the firm scope–innovation question by looking at the effects of business group membership on firm innovation. They find that group membership has a dual effect on innovation. As they note (p. 1348): "While groups facilitate innovation by providing institutional infrastructure, groups also discourage innovation by creating entry barriers for non-group firms and thereby inhibit the proliferation of new ideas". This paper also draws attention to the fact that differing corporate structures may be yet another, but relatively under-researched, determinant of innovative activity.

A primary concern in this literature is the direction of causality. Research activities can open up new avenues for firms (Ahuja & Katila, 2004; Chatterjee & Wernerfelt, 1991; Nelson, 1959) and firms can expand into new businesses as a result of these new opportunities (Baysinger & Hoskisson, 1989; Chatterjee & Wernerfelt, 1991). Thus, R&D activities can also cause firms to diversify (Silverman, 1999). However, most of the models in this literature are cross sectional (Baysinger & Hoskisson, 1989; Hoskisson & Hitt, 1988; Link, 1982; McEachern & Romeo, 1978) and do not control for this possibility. One issue worth noting is that there is a basic lack of correspondence between two key sources of data used in studies in this area. Patent data are classified by technology classes but industries are classified from a product market perspective. To push work along on the issue of firm scope and innovation it would be useful to have a correspondence or concordance that can link technologies to industries. In fact, Silverman (1999) has developed such a concordance that can be a useful tool for researchers in this arena.

Summary. Research on the effect of diversification on firm innovation efforts and output has not provided conclusive results. Arguments are made both for and against the "diversification" hypothesis which states that greater diversification leads to greater investments in research. What research has established however is that both sides of the debate need to be nuanced. The diversification hypothesis applies more to basic research than to applied; however most of the research conducted by firms is applied in nature. Arguments against the hypothesis need to provide a comparative analysis with single business firms that are also evaluated on financial metrics. Resolution of these competing arguments probably awaits the identification of some interesting contingency variables to highlight the conditions under which one effect trumps another. More rigorous empirical tests of the inverted-U relationship which also accommodates the possibility of reverse causality, perhaps in a longitudinal setting, are also required.

2.3 Access to External Knowledge: Alliances and Networks

Introduction. For a relatively long time, cooperative linkages between firms in the innovation process received little attention from traditional economists (Teece, 1992). There are at least two identifiable reasons for this neglect. First, neoclassical economics has traditionally adopted a narrow conceptualization of firms, treating them as identically endowed, abstract, instantaneously adaptive entities with fungible resources (Nelson & Winter, 1982, pp. 6–11; Teece & Winter, 1984). Consequently, most of the features of firms that necessitate cooperation or ensure that it is beneficial, such as non-imitable skill or resource complementarities between firms, are assumed away. Second, economics has long viewed competition as a force that leads to optimal solution of the problem of economic performance (Arrow & Debreu, 1954; Scherer & Ross, 1990; Smith, 1776; Teece, 1992). Collaboration between firms is seen as a potential subversion of this competitive ideal and discouraged or at least viewed with some suspicion (Scherer & Ross, 1990; Teece, 1992). With these premises, inter-firm cooperation appears both unnecessary and undesirable, an outlook that was consistent with both the limited amount of research focused on this area until the mid 1990s and its predominant thrust, the antitrust and policy implications of cooperation (Harrigan & Newman, 1990).[3]

On the other hand, other traditions in economics, and the management disciplines such as strategy and organization theory, have used different models of the firm (Conner, 1991; Nelson & Winter, 1982; Wernerfelt, 1984; Williamson, 1991). These models are in sharp contrast with the older, neoclassical view on both counts mentioned above. First, these approaches explicitly recognize limitations in the capabilities of firms, arising out of history and managerial choices (Barney, 1986; Nelson & Winter, 1982; Prahalad & Hamel, 1990; Williamson, 1991).[4] Second, these approaches, in general, stress the efficiency motivations for cooperation (Hamel, Doz, & Prahalad, 1989; Jorde & Teece, 1990; Kanter, 1989; Mitchell & Singh, 1996; Teece, 1992; Williamson, 1991), rather than its anticompetitive possibilities (Pfeffer & Nowak, 1976). Accordingly, there is an increasing, well-developed research tradition examining the phenomenon of cooperation in these disciplines. This literature has examined the effects of collaboration on innovative output in a significant manner.

In the past few years, the management literature on innovation has paid significant attention to inter-firm collaboration as a determinant of firm innovativeness (Ahuja, 2000a; Kogut, 1988; Lane & Lubatkin, 1998; Mowery, Oxley, & Silverman, 1996, 1998; Powell et al., 1996; Sampson, 2005, 2007). This corresponds with the increasing use of collaborative arrangements by firms to boost their innovative performance especially in high technology sectors of the economy (Hagedoorn & Schakenraad, 1990; Mowery, 1989; Osborn & Baughn, 1987; Whittaker & Bower, 1994) such as information technology (Elfenbein & Lerner, 2003; Sampson, 2005), materials and biotechnology (Baum, Calabrese, & Silverman, 2000; Stuart, 2000).

The relationship between innovative outputs and collaboration has emerged as one of the most fecund areas of investigation in the management literature on innovation in the past two decades, and probably merits a significant discussion. The resultant research has identified at least three distinct effects of inter-firm collaboration on firm innovation performance. First, taken as individual linkages, collaborations provide direct benefits to the participating firms through scale economies in research, reduction of wasteful efforts, sharing of knowledge (Grossman & Shapiro, 1986; Jorde & Teece, 1990), and combining of complementary skills from different firms (Arora & Gambardella, 1990, 1994b; Shan et al., 1994). Second, taken collectively, the linkages within an industry form an information network within the industry and thus facilitate knowledge spillovers. Firms which form linkages gain access to this network and depending upon the attributes of their position in this network, enjoy access to knowledge and increased innovative productivity. Third, the structure of this network affects the rate at which knowledge travels between firms. Over time, as the structure of the network changes, so does the total information that flows through it. Industries in which, and periods when, the network is well connected are marked by greater information transmission than industries and periods marked by a fragmented network. Empirical support for these, however, varies with the first two propositions being subjected to significant testing (and generally finding support) versus the third which remains virtually untested.

Having discussed the structure of networks of collaboration at a broader level earlier in this essay, in this section, we concentrate on how collaborative arrangements at the firm and dyadic level influence the innovative activity of firms as well as how firms' positions on industry networks influences their innovative effort and output. We therefore separate our review into two parts, the first focusing on those studies that examine the impact of inter-firm collaboration on firm innovation but do not invoke a network perspective, and the second focusing on implications of firms' presence in networks.

Inter-firm linkages can be related to innovative efforts as well and they are thus a valid argument for the research production function (see for instance, Bozeman, Link, & Zardkoohi, 1986; Grossman & Shapiro, 1986). Cooperative activity can be seen as a partial solution to the problems of appropriability and free-riding (Grossman & Shapiro, 1986). Collaborative research can thus address the schism between private and public returns to knowledge investments created by uncompensated knowledge spillovers. However, much of the work on the relationship between collaboration and innovation incentives has been done by economists and is, or will be, covered by surveys of that literature (Arora & Gambardella, 2008; Cohen, 1995; Cohen & Levin, 1989; Gilbert, 2006). Hence, here we focus purely on the relationship between collaboration and innovative output.

Since this is one of the more fecund research areas in innovation within the management domain, it may be useful to build a simple model that can serve to hang together the research in this area. To facilitate exposition, we use a reduced form of the innovation production function, which has R&D as its only argument. Thus, innovation performance (P) is a function of R&D inputs: P = *f*(R&D). Using the innovation production function, P = *f*(R&D), as an abstracting construct, we note that innovation performance (P) depends fundamentally on two entities: the value of the argument, innovative inputs or R&D, and, the properties of the transformation function (*f*). The benefits of knowledge sharing, complementarity and a favorable position in the network arise through enhancement of the innovative input, R&D, while the advantage of scale economies arises from the properties of the function (*f*). In each of the two sections discussed below—one on the dyadic relationships between firms and the other on the position of a firm in a network—we build on this simple exposition to tie in and explain this diverse and vast literature.

Dyadic alliances. Multiple mechanisms can be identified to relate collaboration to innovation output. First, collaboration increases a firm's knowledge inputs into the innovation process, by enabling it to *leverage* its contributions to an R&D pool. When firms collaborate, the resultant knowledge is available to all partners, given the public good nature of knowledge. Thus, each partner can receive a greater amount of knowledge from a collaborative project than it contributes to it. Second, cooperation between partners that bring together dissimilar skills can enhance this leveraging effect significantly, as each partner can benefit from complementarity in addition to the knowledge sharing benefits identified in the first case. Third, if the technology of research is characterized by increasing returns to scale, then even minor enhancements in the knowledge of firms through collaboration can lead to significant increases in innovation output. These arguments clearly suggest that under very general and reasonable conditions, collaboration should have a positive impact on innovative output. In our discussion, we also examine some of the assumptions underlying the first three arguments to suggest that even though linkages may provide all the benefits described earlier, the relation between linkages and innovation performance might not be linear. Below, we develop a simple model that enables us to flesh out these various effects and then elaborate on each of these in turn.

Collaboration can influence innovative output by affecting the "effective" levels of innovative inputs (Katz, 1986). A firm's "effective" R&D represents the firm's knowledge pool and consists of its units of internal R&D plus any R&D units it benefits from through collaboration (Katz, 1986). Internal R&D units are completely available to the firm, and are therefore, in entirety, a part of the firm's "effective" R&D. The exact contribution of collaborative R&D efforts to "effective" R&D is not as clear.

Collaborative R&D efforts enable firms to combine knowledge. Given the public good nature of knowledge, this implies that they increase the knowledge pool for all firms involved in the collaboration. In an ideal case, the sum of all collaborative efforts should be available as an input to all firms. Thus, if two firms contribute an amount of $\$x$ each to a collaborative R&D effort then $\$2x$ should be the amount of collaborative R&D available to each firm, in addition to any internal R&D done by each firm. Yet, there are reasons to believe that the full benefits of this pooling are unlikely to accrue to any firm, and that the final contribution of collaborative R&D to a firm's effective R&D may be significantly less than the sum of all the collaborator's efforts.

At least four arguments suggest that the sum of collaborative contributions may not be available in its entirety as a component of effective R&D. First, R&D across organizational boundaries entails significant additional coordination, monitoring, and management costs (Harrigan, 1985; Mitchell & Singh, 1996). Hence, a greater proportion of collaborative R&D expenditures may be assigned to non-productive inter-organizational coordination tasks, thus reducing the amount available for actual research effort (Contractor & Lorange, 1988). Second, R&D conducted in cooperation subsequently needs to be internalized by the parent firm. There may be significant costs to effecting such a knowledge transfer from the collaborative R&D project to the firm (Harrigan, 1985; Teece, 1982). Third, collaboration may not be able to eliminate completely the duplication of research efforts. Some elements of a collaborative research program may therefore require to be at least partially redone within the firm (Grossman & Shapiro, 1986; Harrigan, 1985). Finally, collaboration may lead to strategic behavior on the part of collaborators (Harrigan, 1985; Khanna, Gulati, & Nohria, 1998; Oxley, 1997; Oxley & Sampson, 2004). For instance, a collaborator may send only relatively inefficient researchers, thus providing qualitatively poor inputs even when meeting the quantitative requirements of the project (Contractor & Lorange, 1988). For all these reasons, a unit of R&D done outside the firm may contribute less to the firm's knowledge base than a comparable unit conducted inside the firm.[5] Accordingly, only a part of the total collaborative R&D may be includable as "effective R&D" for the individual firms.

Effective R&D can thus be represented as a sum of internal R&D ($R\&D_{INT}$) and the obtained cooperative R&D benefit, where the latter depends on (a) total collaborative R&D by all firms ($R\&D_{COLLAB}$); and (b) a factor of proportionality (θ) which reflects the degree to which a unit of R&D conducted in collaboration is equivalent to a unit of R&D conducted internally. If θ = 1, then collaborative R&D units are identical to internal R&D units in their contribution to the firm's knowledge base. On the other hand if θ = 0, the firm gets no benefit from the collaborative R&D. A negative θ implies that collaborative R&D is reducing even the services available from a firm's internal R&D. In symbols:

$$R\&D_{EFF} = R\&D_{INT} + \theta^{*} (R\&D_{COLLAB}) \quad (3)$$

Equation (3) summarizes the benefits and costs of knowledge sharing. If we assume that the total R&D budget of a firm can be divided into two components, internal R&D ($R\&D_{INT}$) and cooperative R&D ($R\&D_{COOP}$), then $R\&D_{COLLAB}$ is the sum of $R\&D_{COOP}$ for all participating firms. A firm's contributions to collaborative research are leveraged by contributions from other firms, hence $R\&D_{COLLAB}$, the pool of potential knowledge available to the firms, is greater than its own contribution, $R\&D_{COOP}$. Yet, this increased knowledge base might not be available in its entirety to the firm due to the factors reflected in the θ above. Whether collaborative R&D enhances a firm's effective R&D or not, depends on the value of the parameter, θ. For values of θ close to 1 collaborative R&D will enhance effective R&D. As θ becomes smaller the benefits of collaboration decrease. If we assume that firms will maintain only those relationships where θ is high enough, then cooperation should lead to an increase in effective R&D.

Dyadic alliances, effective R&D and complementarity. Firms have a comparative advantage in conducting sets of similar activities (Masten, Meehan, & Snyder, 1991; Richardson, 1972; Rotemberg & Saloner, 1994). This advantage is based upon the notion that firms have intrinsically limited repertoires of competencies (Coase, 1937; Dosi, 1988; Hannan & Freeman, 1989; Nelson & Winter, 1982; Prahalad & Hamel, 1990) . Developing multiple competencies (Abernathy & Clark, 1985; Arora & Gambardella, 1990; Ohmae, 1989; Penrose, 1959; Richardson, 1972), or maintaining them in the face of rapid technological change (Langlois, 1992), are both difficult for firms, and firms attempting to do so risk poorer performance (Hoskisson & Hitt, 1990; Mitchell & Singh, 1996; Ramanujam & Varadarajan, 1989; Rumelt, 1974; Singh, 1993). Therefore, ideally, firms would prefer to use only a limited set of "closely similar" skills and build a specialized competence in them (Richardson, 1972).

However, technology may demand the simultaneous use of different sets of competencies (Mitchell, 1989, 1991, 1992; Pisano & Mang, 1993; Pisano & Teece, 1989; Pisano, 1990; Teece, 1986). Firms then face a choice of buying or developing the dissimilar competencies, or obtaining them through collaboration (Rothaermel & Boeker, 2008). Transaction costs may make purchase of certain technologies unfeasible (Mitchell & Singh, 1996; Teece, 1989; Williamson, 1985), leaving internal development and collaboration as the only viable alternatives.

Firms faced with this choice can either "go it alone" and divide their resources between their arena of expertise and the new competence required by the industry, or, they can team up with another firm that already possesses the second set of skills but needs the skills possessed by this firm. One way to evaluate this trade-off from the perspective of firms facing such a choice is to compute the impact of both decisions on the "effective" R&D of the firms.

If we assume that firms cannot develop multiple competencies equally effectively, it is likely that the cost of internal development of a unit of the new, dissimilar technology for each firm (C_D), will be greater than the cost of an equivalent unit of similar technology (C_S) for each firm. If the firms decide not to cooperate and, therefore, each firm develops both similar and dissimilar technology, its total R&D budget, say, B, if split equally between the similar and dissimilar activities, provides ($B/2C_S + B/2C_D$) units of R&D. This figure thus represents the effective R&D in the absence of collaboration.

On the other hand, if the two firms collaborate and contribute half their R&D budget to a joint project, each of them retains the same level of internal R&D in the similar technology, but each also gains the benefits of collaborative R&D in the dissimilar technology. Since they collaborate, each firm can bring its own expertise to bear on the collaborative project and instead of individually facing the cost of dissimilar activities, each firm faces only the cost of similar activities. Thus, with collaboration each firm obtains an effective R&D of ($B/2C_S + \theta B/C_S$) units, where θ measures the equivalence between internal and collaborative R&D as before. Hence, each firm obtains a collaborative benefit of $\theta B/C_S$ units, while giving up $B/2C_D$ units of internal research. In such a situation for collaboration to result in enhanced effective R&D relative to the non-collaboration case we need, $\theta B/C_S - B/2C_D > 0$, or, equivalently, $\theta > C_S/2C_D$.

This simple computation provides three significant insights. First, we note that as $C_S < C_D$ by definition, any value of $\theta > 1/2$, leads to increased "effective R&D" relative to the case of no collaboration. Thus, even if collaboration entails managerial and coordination costs of up to half the value of the project, the firms are still better off collaborating, rather than not collaborating. Second, we note that the break-even condition, $\theta > C_S/2C_D$, relates θ to the *ratio* of costs between similar and dissimilar activities. If the costs of developing capabilities diverge widely between similar and dissimilar activities, collaboration can be supported as an optimal choice for extremely low values of the parameter, θ. For instance, if the costs of developing a unit of dissimilar technology are, on average, twice as high as the costs of developing a unit of similar technology for a firm, any θ above 0.25 will lead to an increase in effective R&D through collaboration. Hence, fairly high levels of organizational, management, and knowledge transfer costs can be borne and still leave the collaborators better off, if the technologies require markedly different competencies.

Third, we note that collaboration between two firms with different capabilities in a complementary project leads to a greater increase in effective R&D than collaboration between two firms with similar capabilities in a similar knowledge-sharing project, other things being equal.[6] To see this, note that collaboration provides a net benefit of $\theta B/C_S - B/2C_S$ in the case of collaboration between firms in similar activities, as a firm gives up $B/2C_S$ units of internal R&D to obtain $\theta B/C_S$ units of collaborative R&D. In the comparable case of collaboration between firms with dissimilar competencies the net benefit realized is $\theta B/C_S - B/2C_D$, as a firm gives up $B/2C_D$ units of internal R&D, to obtain $\theta B/C_S$ units of collaborative R&D. As $C_D > C_S$, by definition, we have $\theta B/C_S - B/2C_D > \theta B/C_S - B/2C_S$. Thus, linkages between firms with dissimilar skills in a complementary project will be more beneficial than linkages between firms sharing similar knowledge. Intuitively, this result follows from the fact that linkages of the latter kind produce only a knowledge sharing benefit, but linkages of the former kind provide the additional benefit of complementarity. Thus, we note that under fairly general conditions, collaboration between partners with dissimilar skills, can provide significant augmentation of a firm's knowledge inputs and, consequently, lead to a positive impact of collaboration on innovation performance. We next investigate the mechanism that converts these knowledge inputs into innovative outputs, the transformation function, *f*.

Dyadic alliances, effective R&D and scale. Scale economies in research affect innovative productivity through the transformation function, *f*. We noted earlier that, for appropriate ranges of θ, collaboration results in *enhanced effective R&D*. The scale characteristics of the transformation function *f* determine the degree to which *enhanced effective R&D* results *in enhanced innovation output*. If the technology exhibits increasing returns to scale, increases in inputs are rewarded with more than proportionate increases in output. If the technology exhibits constant returns to scale, increases in inputs are rewarded with proportionate increases in output. If the technology exhibits diminishing returns to scale, increases in inputs are rewarded with less than proportionate increases in output.

In the research process, scale economies can arise if larger projects generate significantly more knowledge than smaller projects. For instance, a particle accelerator built on a larger scale may provide many more insights than two particle accelerators of half the size. Alternately, an integrated circuit design project may promise faster, and more cost-effective, results if many more engineers can be simultaneously employed. In such cases, a larger-sized project may imply a qualitatively and quantitatively different innovative output than smaller projects. Note that the public good nature of knowledge notwithstanding, increasing returns to scale are not always assured in R&D. Increasing the size of a research project may lead to coordination problems that reduce the innovation output.

Cooperation may enable firms to take advantage of such scale economies if they exist. If individual firms have the wherewithal to invest an amount x, in a given research project, then two firms combining resources can potentially invest twice as much. If the transformation technology is characterized by increasing returns in the fashion illustrated above, such an investment will lead to a more than proportionate return, benefiting both firms significantly.

Thus, the presence of increasing returns to scale can increase the benefits of cooperation, as not only do knowledge inputs get leveraged and increased through cooperation, as in the earlier cases, but the transformation technology rewards these input enhancements with larger output increases. Note, however, that such scale benefits, while desirable, are not necessary for collaboration to result in enhanced innovative output. In fact, constant, and even decreasing returns to scale, are perfectly consistent with a positive impact of collaboration on innovation performance.

To see this, consider the innovation production function, $P = f(R\&D)$. For this general function, the total change in innovative output pursuant to a change in effective R&D is given by the total differential $\Delta P = f'\Delta R\&D$, where f' is the derivative of f with respect to effective R&D expenditures, and ΔP and $\Delta R\&D$, are the change in innovation output and effective R&D expenditures respectively. For collaboration to have a positive impact on innovative output, and be economically justifiable on efficiency grounds, we need $\Delta P > 0$. Recall that collaboration, under a suitable θ, will lead to an increase in effective R&D and therefore, $\Delta R\&D > 0$ for appropriate ranges of θ. Under these conditions, for ΔP to be positive all that is required of the function f is that it be *increasing* in effective R&D. This condition is met by any function that exhibits increasing returns to scale, but can also be met by functions exhibiting constant and even decreasing returns to scale. An illustration of a function with decreasing returns to scale, which meets this criterion is provided by $y=\sqrt{x}$. Economies of scale, while sufficient to ensure a positive impact of collaborative R&D, are therefore not necessary for such an outcome. Further, note that the above inference makes no assumption with respect to the nature of collaboration (i.e. whether it is between similar or dissimilar collaborators). Hence, this result holds even when collaboration occurs between firms providing similar inputs, provided of course that θ falls in the appropriate range.[7]

Research in the industrial economics tradition has emphasized the importance of notable scale economies as an efficiency justification for permitting cooperation between potential competitors (Brodley, 1990). In fact, it has been suggested that the existence of demonstrable scale economies be a precondition for allowing the formation of research joint ventures (Brodley, 1990). Yet, a close examination of the innovation production function reveals that such an argument sets up a higher hurdle for collaborative benefits than is actually necessary from an efficiency perspective, and a much weaker condition may suffice to ensure positive outcomes from collaboration.

Dyadic alliances: key conceptual conclusions. The previous analysis permits some interesting conclusions. First, we note that a combination of an innovation production function that is increasing in effective R&D expenditures, and moderate to high values of θ, are sufficient to ensure that collaboration has a positive impact on innovative output, even in the absence of scale economies or complementarity advantages. Second, to the extent that θ is relatively high, or there exist scale economies, or complementarity benefits, this effect of collaboration on innovation performance is further enhanced. Therefore, under fairly general conditions we should expect a positive impact of collaboration on innovation performance.

Of course, inter-firm linkages may also generate diseconomies. For instance, fragmented research efforts may undermine a firm's distinctive competence (Prahalad & Hamel, 1990). As the firm gets involved in a bigger range of projects there is a possibility of loss of focus. Over time this may result in poorer ability to conduct even *similar* activities, and thereby raise its unit cost of conducting activities even within its competence domain. In terms of the framework described above, this is represented by an increase in C_S. Other things such as B—its total budget for R&D—being equal, a higher C_S would result in a reduction of R&D units available to the firm and hence result in lower effective R&D. Increasing management and organizational costs, loss of focus and specialization benefits, and possibly adverse scale implications limit the benefits from cooperation, as do imperfections in the market for knowledge that provide an upper bound to the benefits that can be obtained from this specialization of innovative effort (Arora & Gambardella, 1994b). All these elements suggest that analysis of the relationship between inter-firm collaboration and innovation output should be an extremely rich arena of investigation as these various relationships are explored and nuanced. The prolific output in this area over the last decade supports this conjecture.

Dyadic alliances: empirical results. Studies attempting to relate the technical performance of firms to their collaborative activity have used many approaches, such as (a) self-reported or survey-based (Brockhoff, 1992; Gemunden, Heydebreck, & Herden, 1992; Niosi, 1993; Senker & Faulkner, 1992); (b) archival or objective results-based (Baum et al., 2000; Harianto & Pennings, 1994; Stuart, 2000); and (c) anecdotal and case study approaches (Harianto & Pennings, 1990; Link & Bauer, 1989; Olleros & Macdonald, 1988). Many other kinds of measures have been used, such as perceptual (Brockhoff 1992; Niosi 1993; Senker & Faulkner 1992), those based on physical outputs such as new products (Gemunden, Heydebreck & Herden 1992), and patents (Sampson, 2005; Mowery et al., 1996).

The survey-based studies, in general, find a positive impact of cooperative activity on technical performance (Gemunden et al., 1992; Hull, Slowinski, Wharton, & Azumi, 1988; Niosi, 1993; Senker & Faulkner, 1992). However, the measures of performance are somewhat amorphously defined in some studies. For instance, Niosi (1993) uses percentage of firms claiming benefits of cooperation versus those claiming disadvantages, as a measure of collaboration effectiveness, while Senker and Faulkner (1992) use impressionistic measures from a sample of 35 managers. In addition, the evidence is descriptive rather than inferential (Niosi, 1993; Senker and Faulkner, 1992). Brockhoff (1992) presents inferential evidence but relates perceptions of success only to perceived transaction costs. No effort is made to relate benefits to technological or strategic dimensions of cooperation. Harianto and Pennings (1993) look at adoption of innovations as a performance outcome relatable to the formation of cooperative linkages and find that innovation adoption is more feasible if a firm has developed inter-firm arrangements. The case study approaches recount both successful and not-so-successful examples of cooperative activity (Harianto & Pennings, 1990; Link & Bauer, 1989). Gemunden et al. (1992) is one of the few studies in this genre that relates physical outcomes, such as number of new products developed to the formation of cooperative linkages, in the context of a large sample statistical analysis. While they find support for a positive impact of cooperation on innovation performance, their research design, methodology, and sample are all restrictive. They examine firms operating in a single geographic location, rely exclusively on self-reported data, and use a multi-industry cross-section. However, not all results in this genre are supportive of the argument that collaboration increases innovativeness. Kotabe and Swan (1995) for example, find surprisingly that firms that engaged in more cooperative arrangements with other firms, produced innovations that were less novel and had less impact. Hence, while inter-firm relationships may lead to a greater number of innovations, it is not clear from the evidence that the quality of such innovations is better than those that firms with less collaborative arrangements produce.

The conclusion that more collaborative linkages help increase the amount of innovations produced by the firms is not always supported. While Baum et al. (2000) found that the number of alliances at founding increased patenting activity of firms in their sample of biotech startups in Canada, and Ahuja (2000a) found a positive effect of ties in the chemicals industry, Stuart (2000) found no evidence of any effect of the number of alliances on a firm's patenting activity in a different sample. Scholars have therefore examined a number of characteristics of the inter-firm relationship, beyond simply the number of linkages, that may affect the innovativeness of firms. Among the prominent factors pertaining to the dyadic relationships argued to influence a firm's innovative output are: the capability of the partner (Stuart, 2000); the absorptive capacity of the firm in isolation (Mowery et al., 1996) as well as in relation to its partner (Lane and Lubatkin, 1998); the diversity in the portfolio of relationships (Baum et al., 2000); the technical distance between the firm and its partner (Sampson, 2007); the governance mechanism employed in the relationship (Sampson, 2004); and prior experience with alliance relationships (Sampson, 2005; Hoang & Rothaermel, 2005). Overall, it is found that absorptive capacity of the firm (Lane & Lubatkin, 1998; Mowery et al., 1996) and the technical capabilities of the partner increased innovative output of the firms. Sampson (2007) found that equity joint ventures enabled transfer of knowledge and that moderate divergence in technical abilities between the partners rather than too much or too little was best for innovative performance. Experience with alliances leads to better performance (Sampson, 2005) but it is general experience with alliances rather than partner-specific experience that drives this outcome (Hoang & Rothaermel, 2005). Failing to adopt the "appropriate organizational form" is associated with a performance penalty (Sampson, 2004).

Note that while we have learnt a lot about the alliance innovation relationship, many basic results still remain untested. Indeed, the implications of the simple model we laid out earlier have only partly been confirmed. While the preponderance of evidence suggests a positive effect of alliances on innovative output (though see caveats below) the separate effects of scale versus complementarity remain unexplored. Similarly, while cooperative ties have been argued as means to cross technological frontiers (Rosenkopf & Almeida, 2003), scholars have so far not paid as much attention, either theoretical or empirical, to the quality and kind of innovations that firms produce as a result of their ties.

Alliance studies on innovation have faced significant empirical hurdles that may limit the conclusiveness and interpretation of their results. For instance, matching innovations (or failures to innovate) directly to the alliances has proven to be extremely difficult, as separation of alliance related and non-alliance related innovation is generally not possible in a large sample longitudinal study. This raises the possibility of aggregation or ecological fallacies (Sampson, 2007). Similarly, obtaining data to control for the level of investment made by the firms in R&D has not always been possible, especially for studies that look at smaller firms (Stuart, 2000). Recognizing the central role of R&D as a control variable here (as the discussion on the innovation production function made clear) suggests that the point estimates on the returns to alliance activity may be interpreted only very limitedly. Studies also show that firms that are lacking either in technological merit or commercial capabilities (Ahuja, 2000a; Oxley & Sampson, 2004) tend to form greater numbers of alliances. This raises the possibility of reverse causality, instead of alliance activity influencing innovative output, it may be the reverse. Controlling for the propensity and ability of the firms to enter into alliances is critical for robust causal explanation. However, while studies have often used Heckman type models to address this issue, this practice is not universal. Further, even with such models, error structure assumptions are very rarely met by the data, hence necessitating the substitution of simplification of one kind over another. To add to the problem, identifying assumptions are necessary to estimate the model and in most cases it is difficult to get defensible exclusion restrictions (by identifying variables that logically enter the sample equation but not the productivity equation and *vice versa*).

That said, even though causality may be difficult to ascribe firmly in most studies, stylized empirical regularities are useful in themselves, and the literature has done a good job of providing these. Hamel (1991) also suggests that firm intentions in going into the relationship influences what the firm gets out of the relationship. For instance, Ahuja (2000b) found that firms that had both technological and commercial capital were less interested in forging relationships, presumably because they had less hope to achieve complementarities through the relationships. These studies suggest that the effect of cooperative arrangements on innovativeness would also be affected by the intentions of the firm to go for an alliance in the first place which in turn, may be influenced by the portfolio of activities possessed by the firm; further examination of this suggestion may surely yield insights into the mechanisms through which firms use cooperative arrangements to increase their innovative output.

Network position. The previous section focused on the impact of individual linkages on the innovation performance of the firm. The next section analyzes the significance of a larger entity, the network comprised of all such inter-firm linkages, for the innovation performance of individual firms within the network. The central thesis of this section is that, taken collectively, the network of linkages serves as an information conduit for the industry (Clarysse, Debackere, & Rappa, 1996; Debackere, Clarysse, & Rappa, 1996). Information flows through the links of the network and the degree to which any firm participates in this information flow, is determined by its position on this network. Firms with higher centrality and range in this network enjoy greater access to the information flowing through the network, relative to firms that are peripheral or linked to homogenous or deeply interconnected partners.

Networks and effective R&D. To understand the genesis of this network effect it is useful to relate it to the innovation production function. Earlier in the paper we noted that cooperative linkages affect a firm's innovation performance by increasing the firm's "effective R&D", the key argument to the innovation production function. This increase in effective R&D occurs through the collaboration advantages of knowledge sharing and complementarity, which enable a firm to leverage its own contributions to a collaborative R&D pool. In this section we examine another source for increasing effective R&D, access to *knowledge spillovers* in the industry.

It is widely accepted that knowledge flows between firms and industries are constituted of both contractual knowledge transfers and relatively informal, uncompensated knowledge "spillovers" or leakages (Bernstein, 1989; Bernstein & Nadiri, 1989; Debondt, Slaets, & Cassiman, 1992; Ghemawat & Spence, 1985; Jaffe, Trajtenberg, & Henderson, 1993; Levin & Reiss, 1988; Mansfield, 1985; Nelson & Winter, 1982; Quintas, Wield, & Massey, 1992; Rappa & Debackere, 1992; Vandierdonck, Debackere, & Rappa, 1991). Accordingly, a firm's effective R&D includes not just its internal and cooperative R&D inputs, but also its access to knowledge spillovers (Katz, 1986). A firm's total effective R&D can thus be represented as a sum of three components, its internal R&D, a measure of its access to collaborative R&D, and a measure of its access to knowledge spillovers.

$$R\&D_{EFF} = R\&D_{INT} + \theta * (R\&D_{COLLAB}) + \gamma * (R\&DSPILLOVERS)$$

Past research on spillovers has identified some of the mechanisms through which spillovers potentially occur. Prominent among these mechanisms are geographic proximity, scientific conferences, journal and patent publications, vendor relationships, and personnel movements (Antonelli, 1994; Feldman, 1993; Jaffe et al., 1993; Lazonick, 1993; Marshall, 1919; Quintas et al., 1992; Rappa & Debackere, 1992; Rosenkopf & Almeida, 2003; Vandierdonck et al., 1991). The central premise of the network approach is that informal knowledge transfers can occur through the network of inter-firm relationships.

The argument relating inter-firm linkage networks to knowledge spillovers consists of two central notions. First, that the inter-firm linkage network serves as an information conduit and facilitates knowledge spillovers between firms by carrying information from one firm to another. Second, that the attributes of a firm's position on this network provide a measure of a firm's access to these spillovers and can be regarded as a contribution to its effective R&D, and hence to its innovation performance. We elaborate on each of these propositions in turn.

Network as information-conduits. To understand how the network of inter-firm relationships can serve as a mechanism for knowledge spillovers it is important to understand the process by which information flows through the network (Ahuja, 1996; Ahuja 2000a). The essence of the network-as-information-conduit approach can be stated in four central premises: (1) when people meet, they often talk; (2) the context in which people meet determines significantly the issues they talk about; (3) each person carries away from a conversation, at least potentially, some "new" information which can be used in subsequent conversations; and (4) to the extent that a person engages in conversations with many partners, she carries to each conversation a memory of some elements from conversations with other partners. Thus, in each conversation a partner can obtain new information from the knowledge the partner picked up through her interactions with all her other partners.

Scientists attending a conference provide a simple illustration of this process. Two scientists who find themselves in each other's company at a scientific conference are likely to strike up a conversation. It is also probable that their conversation will focus significantly on the issues the conference deals with, rather than general social, political or personal concerns. In the course of such a conversation, it is possible that at least one scientist, and perhaps both, learn something they were previously unaware of. Finally, it is likely that these scientists meet other scientists at this conference. Knowledge gained at this conversation may then be transmitted to other parties who may be unaware of it and, equally possibly, knowledge gained by others can reach the parties to this conversation by a similar process.

The network of interfirm linkages provides a similar, though perhaps stronger, illustration of the processes described above. Collaborative linkages, by definition, are more than chance encounters. They represent arenas of sustained, focused, and intense interaction (Ahuja, 2000a; Auster, 1992). Linkages represent sustained interaction in that they involve repeated and regular interaction between the partners rather than a single meeting. Sustained interaction implies that inter-firm linkages represent strong ties (Granovetter, 1973, 1982), i.e., ties marked by frequent and intense communication. They are focused in that the objectives of collaborative activities are reasonably well specified, and the parameters of interaction and interest are clearly demarcated. Finally, they are intense in that they entail coordination, close contact, and mutual dependency. Intense interaction provides an opportunity to share information (Boorman, 1975; Granovetter, 1973, 1982; Krackhardt, 1992). Thus, inter-firm alliances can be identified as an important channel of communication between the firm and its directly tied partners.

An inter-firm linkage is also a firm's link to many indirect partners (Mizruchi, 1989). To the extent that a firm's partners are involved in linkages with other partners, they bring to their interaction the wealth of their experience from interactions with these other partners (Gulati, 1993). This mechanism makes possible the fact that information originating with parties not directly linked to the firm can still reach the firm if they share common partners. Thus, a firm's linkages provide it with access not to just the knowledge developed by its partners, but also to the knowledge held by its partner's partners.

If many firms in an industry form such linkages, and a similar process works in the interactions of all firms, then information can make its way from one firm in one part of the network to another firm in another part of the network. Information can travel either directly through the firms' links to each other, or through their links to common third parties. In this sense, the network, which is the accumulation of individual linkages, serves as a communication channel for the network members, with each node, or firm, on the network being both a recipient and a transmitter of information (Rogers & Kincaid, 1981, p.76).

An alternate approach to understanding the role of the network-as-information conduit is to think of the network as an abstraction of the underlying patterns of communication in the industry. Knowledge spillovers occur when communication travels from one firm to another. The precise communication patterns are unknown and difficult to trace. However, the existence of interfirm linkages provides us with a road-map indicating one set of paths of relatively dense communication between firms. The network thus serves as a proxy for the real, but unobserved, communication patterns in the industry. The previous depiction of the network as an information channel, and the role of both direct and indirect links in facilitating information exchange, has been widely documented in many contexts. Studies of labor markets reveal that the network connections of an individual are important sources of information, and determine both the likelihood of obtaining a job and the realized remuneration, even after controlling for ability and formal job search procedures (Granovetter, 1973, 1974; Montgomery, 1991, 1992, 1994). Studies of technological communities (Rappa & Debackere, 1992; Rogers & Larsen, 1984) support this thesis.

In an insightful study of the microelectronics industry, Rogers and Larsen (1984) found that network ties (at the individual level) were not just contributors to the solution of technical problems, but in many cases were the most important sources of information in resolving them (Rogers & Larsen, 1984). Further, they found that the existence of this network of formal and informal contacts between individuals, and its importance as a source of information, were both clearly recognized by engineers and scientists. Some of the experiences recounted by the managers in their clinical studies provide vivid illustrations of the processes described earlier in this section. The notion that the network implies resources through both direct and indirect ties, that it carries relevant information, that context of communication determines content of communication, are all described in these experiences (Rogers & Larsen 1984, pp. 80, 84). Leonard-Barton (1984) and Gulati (1993) also provide similar illustrations of communication flows across social communities formed through professional ties. Thus, the thesis that the network serves as an information conduit finds support in a broad range of empirical contexts.

The impact of position in the network. The second critical element of the argument concerns the impact of *network position* on innovation performance. The literature suggests that the information benefits of a network accrue in three forms: access, timing, and referrals (Burt, 1992). In the context of innovation-related knowledge spillovers, all of these benefits are relevant. Firms with superior *access* enjoy advantages in terms of information collection and information processing. Individual firms can pursue only a limited number of technologies and lines of research (Badaracco, 1991).

Having superior access, or a large catchment area for information, confers an advantage in two forms (Freeman, 1991). First, the network serves as an information gathering device. Superior access implies firms can receive information on the success and failure of many more research efforts than other firms which have more limited access (Rogers & Larsen, 1984). Second, the network serves as an information processing or screening device (Leonard-Barton, 1984). Each additional node that a firm has access to can serve as an information processing mechanism, absorbing, sifting, and classifying new technical developments, in a manner that goes well beyond the information processing capabilities of a single firm (Ahuja 2000a; Burt, 1992). Keeping abreast of the literature in even limited specialties can tax the information processing capabilities of most firms (Badaracco, 1991; Hausler, Hohn, & Lutz, 1994). Having an "army" of trackers, in the form of a network of contacts, reduces the cognitive and organizational dimensions of the task (Burt, 1992; Hausler et al., 1994). Relevant developments may be brought to the firm's attention through its links (Freeman, 1982, p. 124). Alternately, a firm can activate its network to identify the sources that are likely to be well informed about an issue (Freeman, 1982, p. 124). It is clear that with this mechanism, both the number of ties as well as their distribution across partners would be relevant. This basic insight has driven research on partner diversity and structural holes (see next section).

Equally critical in the context of innovation are the *timing* benefits of an information network. Patenting is a game of "getting there first". Obtaining timely information can often mean the difference between crossing the finish line first and dropping out altogether (Reinganum, 1989). A firm's network relationships can apprise it of new technical developments long before they become common knowledge in the industry. In many industries the gap between a discovery or invention and its formal diffusion through patent disclosure, reverse engineering or other procedure may take years (Almeida & Kogut, 1999). The network can provide gossip leads and information with a much shorter lag, thus providing early recipients of information with a significant advantage (Rogers & Larsen, 1984). Prior research has shown that in many organizations, a few highly competent individuals are explicitly devoted to the surveying and transmission of technical developments (Allen, 1977). Meetings between such "gatekeepers" in different firms can be an especially efficient process for timely information diffusion in the network (Allen, 1977; Leonard-Barton, 1984).

Obtaining information on technical developments is only one part of the story. Utilizing that information optimally is equally relevant (Arora & Gambardella, 1994b; Burt, 1992). This draws attention to the *referrals* advantage of a network. The most critical R&D asset in many industries is people, and identifying appropriate personnel is repeatedly cited as a critical component of the process of innovation (Freeman, 1982). A firm may have only limited absorptive capacity, and the ability to maximally exploit available information may lie outside the firm (Burt, 1992; Cohen & Levinthal, 1989). The network provides evaluation and information on many personnel in different firms and thus helps firms to choose appropriate people to resolve technical problems or take advantage of opportunities (Burt, 1992; Leonard-Barton 1984; Montgomery, 1991, 1992, 1994). Past research suggests that such network ties are not just important in the identification and hiring of the individuals embodying a firm's technical competencies, but may in fact be the predominant means of doing so (Leonard-Barton, 1984).[8] The magnitude of this benefit is best realized by noting that the departure of single individuals from corporations in high-technology industries has been associated with significant declines in the market values of companies (Rogers & Larson, 1984). Therefore, firms in favorable positions with respect to identifying potentially good employees are significantly advantaged.

Empirical studies regarding network position. Empirical efforts to test these implied arguments have been conducted by linking network structure with innovative outcomes in the context of large sample statistical analysis (Ahuja, 2000a, 2000b; Debackere et al., 1996; Owen-Smith & Powell, 2004; Shan et al., 1994). Shan et al. (1994) examine a network of biotechnology start-ups and find that for their sample of firms, linkage formation is associated with superior innovation performance, as measured by patenting frequency, but innovation performance has no impact on linkage formation. Debackere et al. (1996) examine the same industry but use a different research design. They use research publications as their measure of innovative output, and relate this to measures of a firm's embeddedness in the network in terms of network parameters such as centrality, in the context of a longitudinal study. They find a positive impact of firm embeddedness on number of publications authored by employees of the firm. However, since they use research publications as the dependent variable, they might have missed capturing many commercially valuable innovations. Further, their study may suffer from selection bias since only those firms that have chosen to publish are included in the sample.

Researchers have also examined the effect of structural holes, a measure of non-redundant ties, on firm innovation. Structural holes account for those ties in which the partners are not connected to each other. Such ties should provide greater diversity in information. However, the results of such studies have been mixed. For instance, Baum et al. (2000) found that network efficiency (diversity of partners across organization types such as hospitals, pharmaceutical companies, etc.), a concept related to structural holes, and network size (number of alliance partners) increased innovativeness of biotechnology start-ups. Similarly, Hargadon and Sutton (1997), in an examination of the process of innovation in a product development firm, found that the firm's "access to dissimilar industries" let it generate new innovations. However, in a longitudinal study of chemical firms that examined the impact of direct and indirect collaborative relations and the structure of relations between directly related partners on the innovativeness of the focal firm, Ahuja (2000a) found that being connected to unconnected partners hurt a firm's innovativeness. He suggests that this might be because of better resource sharing facilitated by trust in a closed network.

While Ahuja's paper seems to suggest that it is better for firms to be in a closed, dense network, Hargadon and Sutton's (1997) paper argues for being connected to dissimilar others. Results such as this have helped the development of a broader debate in the organizations literature between the relative merits of closed versus open networks. However, which form of network is best should be contingent on what the firms want to use the network for (Ahuja, 2000a). One possible resolution suggested for these conflicting findings is that in horizontal networks, as in Ahuja's study, where the competitive motive is especially strong, closed networks may help to generate trust and thus improve information flow. On the other hand, where the network connects firms across several different industries and the competitive motive is weaker, the diversity provided by an open network may be more valuable. A study that directly targets these different types of networks in different contexts to establish or refute this argument is still awaited.

Following the aforementioned logic, network scholars have argued for exploring the contingent value of networks for innovation (Adler & Kwon, 2002; Ahuja, 2000a). Recent research has started exploring the various contingencies that influence the value of networks in general (Hansen, 1999; Owen-Smith & Powell, 2004; Rowley, Behrens, & Krackhardt, 2000; Zaheer & Bell, 2005). These studies, with a few exceptions such as Owen-Smith and Powell (2004) and Hansen (1999), do not directly test the contingent effect of networks on innovation but nevertheless, have important implications for the research on how networks affect innovation output. The major contingencies considered are the nature of task (Hansen, 1999; Rowley et al., 2000), the broader institutional environment (Owen-Smith & Powell, 2004), the geographical spread of the network (Owen-Smith & Powell, 2004) and the resources and capabilities of the firms in question (Zaheer and Bell, 2005).

Hansen (1999) found that strong ties are better than weak ties for transmission of tacit knowledge. Rowley et al. (2000) argue that sparse networks are better in the face of uncertainty and rapid change. Owen-Smith and Powell (2004) suggest that when the network is localized in an area, the membership in that network is what matters and not a particular position in the network. For a network spread through a larger area, the position in the network is more important than mere membership. They also argue that mere membership is more important than position in networks that have a greater percentage of non-commercial organizations as members. A surprising finding in their study is that centrality in networks with smaller geographical span and a greater percentage of public research organizations (such as universities) actually *hurt* the innovative performance of firms. They speculate that this might be because in a smaller network, central commercial firms may be punished for strategically blocking the flows of information. This suggests that the institutional environment such as legitimacy of brokering information may also affect the influence of networks on innovation output (Gabbay & Zuckerman, 1998). Identifying contingency effects in the relationship between network structure and innovation promises to yield many insights in the future.

A more neglected aspect of the relationship between networks and innovation is the costs that networks impose on innovative output (Adler & Kwon, 2002; Hansen, Podolny, & Pfeffer, 2001). Much of the research has focused on the informational benefits of networks while the costs are only implicitly considered if at all (Adler & Kwon, 2002). However, there are many reasons to believe that networks can impose costs on both the innovative performance of a firm and the broader technological progress of all the firms in the network. First, maintaining relationships with firms involves costs because relationships demand reciprocity (Hansen, 1999). To receive information and other resource benefits, a firm also needs to provide benefits which may affect the innovation productivity of the firm (Hansen, 1999). Some studies (Hansen et al., 2001; Lee, 2007) have taken the costs of maintaining ties into account when considering the effects of networks on innovation. For instance, Lee (2007) finds that the size of network has an inverted-U relationship with timing of market entry because at a larger size of the network, the costs outweigh the advantages. Second, while being embedded in a network may reduce the threat of opportunism and can facilitate knowledge and resource transfer (Ahuja, 2000a; Uzzi, 1997), too much embeddedness may also pose problems (Uzzi, 1997). Apart from insulating firms from new information, over-embeddedness may lead to a Not-Invented-Here syndrome which may reduce adoption of new ideas (Adler & Kwon, 2002). Over-embeddedness may lead to free-riding (Uzzi, 1997), which may adversely affect the productivity of research effort. Third, network structures may also adversely influence the technological progress of the broader network. While a network rich in structural holes may provide brokerage benefits to the focal actor (Burt, 1992), brokering information may also prevent information flows in the network and thus hamper innovation (Adler & Kwon, 2002; Gabbay & Zuckerman, 1998). This blockage of information flow may also result in duplication of research efforts and hurt innovation productivity.

Networks can also retard innovation by limiting flexibility. Many interlinked firms may persist with an inappropriate technology as their mutual relationships enable them to survive, at least for short periods of time. Further, change in a highly linked system may be more difficult than change in independent organizations (Glasmeier, 1991). The costs networks impose on innovation need much more examination by network and innovation scholars alike.

Most of the studies that examine the effects of networks on innovation—whether benefits or costs—take the network structure and collaboration ties as exogenous. This may be questionable, especially if firms take an active part in shaping their network (Ahuja, 2000b; Adler & Kwon, 2002). For instance, Ahuja (2000b) found that firms that generated important innovations were more likely to form linkages. Relatively few studies (Lee, 2007) examining the role of network linkages have accounted for a firm's propensity to form a linkage. A more structural approach, which accounts for the propensity to be in a network structure while examining the role of network structures on innovation in a longitudinal setting, is critical.

2.4 Firm Performance

Basic arguments. Organizational scholars (Greve, 2003; Mone et al., 1998; Wiseman & Bromiley, 1996) interested in how firms cope with organizational decline and the factors that affect risk behavior of the firms have proposed that changing fortunes of firms influence the innovative performance of firms. Following the behavioral theory of the firm, they identify firm performance (Greve, 2003) and the amount of slack (Greve, 2003; Nohria & Gulati, 1996) available to the firm as important predictors of innovation in firms. However, scholars differ in whether these variables affect innovation positively or negatively (Mone et al., 1998; Nohria & Gulati, 1996).

Modeling innovations as outcomes of search, scholars (Bolton, 1993; Greve, 2003) argue that performance below aspirations motivates firms to undertake search. These scholars employ the idea of "problemistic search" from the behavioral theory of the firm (Cyert & March, 1963) which states that performance below expectations leads firms to search for new solutions. Greve (2003) found that shipbuilding firms in Japan invested less in innovation when their performance was greater than their aspirations. Following the theory, he measured the aspiration level of firms as a function of the firms' own past performance and the performance of other competing firms. Another theoretical mechanism through which sub-aspirational performance may positively impact innovation is derived from the prospect theory (Tversky & Kahneman, 1981). According to prospect theory, decision makers become risk-seeking when facing losses (Mone et al., 1998; Wiseman & Bromiley, 1996). Assuming risk-taking is positively correlated with investments in innovation, poor performance leads to greater investments in innovative efforts (Mone et al., 1998). However, this assumption has problems. McEachern and Romeo (1978) point out that in certain contexts, not investing in innovation may be riskier than investing in innovation because the risk of investing is limited to the investment while the risk of not investing may be complete erosion of the market (Schumpeter, 1942). Further, in certain organizational fields, not investing in innovation may be norm-defying (Bolton, 1993). Bolton (1993), for example, found laggards more willing than high performers to join R&D consortia when the idea of consortia was new. However, as the idea of research consortia became institutionalized, poor performance had no predictive power in predicting entry into the consortia.

Contrasting with the previous findings, several papers (Cameron, Whetten, & Kim, 1987; Staw, Sandelands, & Dutton, 1981) suggest that organizational decline curtails innovation. The basic argument of these papers is that threat, such as that imposed by poor performance, results in rigidity and conservative behavior (Staw et al., 1981; Whetten, 1981). This "threat rigidity" causes firms to have an inward focus (Whetten, 1981) and forces them to emphasize static efficiency rather than novelty (Cameron et al., 1987; Mone et al., 1998). Hence, innovative efforts are reduced.

In order to reconcile these divergent views, Mone et al. (1998), proposed a contingency model of the effect of organizational decline on innovation. They argue that variables at three levels—environmental, organizational and individual—determine whether "problemistic search" or "threat rigidity" effects dominate in a given setting. Clear empirical tests of the contingency view are still awaited. In a recent study, Chen and Miller (2007) argue that a firm's innovative response to below-par performance is influenced by its proximity to bankruptcy, thereby identifying another contingency factor in the performance–innovation relationship. Katila and Shane (2005) find that certain market conditions do influence whether new firms with no resources are more innovative than established resource rich firms. This study also provides some empirical support for the contingency idea, but the contingency approach needs much more theoretical and empirical development.

Organizational slack differs from organizational performance because slack is a stock variable while performance is a flow variable (Greve, 2003). While a firm's slack is a result of accumulated performance, performance of a slack-rich organization can vary over time. Hence slack changes more slowly than performance and both need not covary (Greve, 2003). Scholars have distinguished between types of slack—absorbed versus unabsorbed (Singh, 1986), for example—and theorized different effects of each on innovation (see Nohria and Gulati [1996] for a review). However, both positive (Greve, 2003) and negative (Nohria & Gulati, 1996) effects of slack on innovation have been hypothesized. On the one hand, slack is argued to allow experimentation of ideas that would not have been approved in times of resource crunch (Cyert &

March, 1963; Nohria & Gulati, 1996) and thereby foster innovation. On the other hand, scholars (Leibenstein, 1966; Nohria & Gulati, 1996) have argued that slack adversely affects the productivity of innovative efforts by tolerating waste and reduced monitoring. Given these two contradicting forces, Nohria and Gulati (1996) hypothesized and empirically verified an inverted-U relationship between slack and innovation.

Future directions. Overall, the research on the effects of organizational performance suggests that performance relative to aspirations is an important predictor of innovativeness in firms. However, the relationship is not so straightforward and may be contingent on several factors at each level of analysis. Research in this area needs stronger theoretical argumentation and empirical tests regarding the contingent nature of performance on innovation. Research on organizational slack appears to have stagnated. With occasional exceptions (Chen & Miller, 2007; Greve, 2003; Nohria & Gulati, 1996) there has been relatively little new activity in this area. One potentially fruitful direction of research may be to investigate more closely the differences between the nature of search processes in the two types of search: problem-motivated search and slack-motivated search. Since the motivations to search differ in both these mechanisms, one may hypothesize that the nature of search may differ. Given the importance of the nature of search (March, 1991)—exploratory versus exploitative—in explaining inter-firm resource differences (Ahuja & Katila, 2004) and in the technical advance of society as a whole (Nelson, 1959), it is important for scholars in innovation to investigate the factors that influence the mix of innovative efforts (Cohen, 1995). The source of motivation of search—slack or problem—may well be one such factor.

3. Intra-Organizational Attributes

3.1 Organizational Structure and Processes

Organizational scholars (Aiken & Hage, 1971; Brown & Eisenhardt, 1997; Burns & Stalker, 1994; Collins et al., 1988; Damanpour, 1991; Galbraith & Merrill, 1991; Hage, 1965; Hage, 1999; Henderson & Cockburn, 1994; Henderson & Clark, 1990; Hull, 1988; Pierce & Delbecq, 1977; Thompson, 1965; Tsai & Ghoshal, 1998), perhaps more so than economists, have delved into the internal workings of firms to identify how the organization of activities affects both the motivations to invest in innovation and the productivity of innovation efforts. This large and burgeoning literature can be broadly divided into two categories: (a) the design of organizational structure and its effect on innovation; and (b) the design of organizational processes and its effect on innovation.

Organizational structure. Organization structure is likely to influence information flows within the organization as well as responsibilities and incentives. Given these attributes, one would expect organization structure to be a key determinant of both innovative efforts as well as innovative inputs. Two broad trends can be identified in the literature that has emerged on the topic. On the one hand, researchers have tried to evaluate the effects of wholistic descriptions of organization structure based on combinations of attributes. Hence, research has identified archetypes of organization structure such as mechanistic, organic, or ambidextrous and tried to identify the implications of such structures for innovation. On the other hand, research has focused on understanding the individual components of organizational structure such as centralization, complexity and formalization and their impact on innovation. We review these trajectories in turn.

Following Burns and Stalker (1994), "organic" structures (characterized by fluid job descriptions, loose organization charts, a low degree of formal, centralized control, and an emphasis on horizontal communication) (Hage, 1999) were considered to be better than mechanistic, bureaucratic organizations (with clearly defined roles, responsibilities and strict controls) from the perspective of innovation (Aiken & Hage, 1971). However, Hull's (1988) study, by arguing that organic structures may be better for smaller firms rather than larger firms and superior only when the technological system is complex, suggests some boundary conditions to the above assertion. Subsequent work has suggested that organization structures for innovation also need to distinguish between incremental and radical innovation (or exploitation and exploration) as a structure appropriate for one may not be ideal for the other (Benner & Tushman, 2003; Smith & Tushman, 2005; Tushman, Smith, Wood, Westerman, & O'Reilly, 2002) and yet organizations may need to conduct both types of activities. Several organizational solutions to this problem have been identified, largely through small sample or qualitative work. The first is the possibility of "cycling" organization structures such that the organization uses an organic design to explore and then switches to a mechanistic design to execute the innovation (Duncan, 1976). Hence, the organization alternates between the two types of structures over time. Westerman, McFarlan and Iansiti (2006) have similarly suggested different organization designs for different stages of the innovation life cycle (Anderson & Tushman, 1990; Tushman & Anderson, 1986).

Galunic and Eisenhardt (1996) draw attention to another possible solution to this problem of matching innovation needs with organization structures: the organization changes the product market charters of individual divisions to match them with the appropriate needs of the products. For instance, laptop computers may be a part of one division in one year but may be switched to another division in a subsequent year. This suggests that, rather than trying to change structures for a given division, firms may change their product-market domain to improve the fit between the business and the structure.

Brown and Eisenhardt (1997) draw attention to yet another structural variation adopted by firms to deal with innovation. Broadly speaking, environments can be characterized by large but infrequent changes (the discontinuous change or punctuated equilibrium setting) or continuous and significant change. Duncan's (1976) solution of cycling organization structures fits with the first context but may be of limited use in the second context. In their study, Brown and Eisenhardt (1997) find that in the computer industry organizations handled the problem of continuous change not through organic structures or mechanistic ones but improvised semi-structures that combine elements of both. Thus, managerial responsibilities and project priorities were clearly defined. Further, these were combined with extensive cross-project communication through formal meetings. However, the actual design processes were left flexible rather than tightly structured. They label these "hybrid" organizational forms that combine some structured features with more free-form interactions as semi-structures.

Tushman and O'Reilly (1997) and Tushman et al., (2002) identify another approach to the solution of this problem, the use of ambidextrous structures that split up the organization into differentiated sub-parts that are connected only at the top-management level. Such organizations have sub-units that are focused on exploitation or exploration and each sub-unit is optimized for its own goal. Thus, instead of units cycling through different organizational structures over time or using semi-structures that are simultaneously both loosely and tightly defined, in ambidextrous organizations loose and tight organization structures simultaneously co-exist but not as hybrids.

In addition to these main themes, at least three other organizational variations have been identified in the context of innovation: skunkworks, spin-outs, and corporate venture capital investments. In skunkworks, a select group of employees or sub-part of the organization is separated from the rest of the organization to provide it with greater autonomy to develop a product or service which is then usually brought back into the organization to be commercialized. In spin-outs (Agarwal, Echambadi, Franco & Sarkar, 2004; Govindarajan & Trimble, 2005; Klepper, 2007), a part of the organization is separated to run a business in its entirety outside the organization (and not just the product development part). A third approach is the use of corporate venture capital investments (Dushnitsky & Lenox, 2005; Wadhwa & Kotha, 2006). The literature has done an admirable job of identifying these various structural solutions; however the frequency of these solutions, the conditions under which they are seen to emerge, their performance implications over the medium to long term as well as their limitations still need to be empirically assessed.

A separate stream of work has focused on individual characteristics of organization structure such as complexity, centralization and formalization rather than wholistic descriptions of structures. Complexity—usually measured by the percentage (Hull, 1988) and the variety (Aiken & Hage, 1971) of employees requiring specialized training—helps innovation by enabling cross fertilization of different ideas (Aiken & Hage, 1971) and by providing the firm with a source of intellectual capital (Hage, 1999). The role of complexity, as defined above, in the generation of technological innovation has however not been a subject of much empirical examination (Hage, 1999).[9]

Decentralization refers to the diffusion of decision-making rights among the organizational members (Hage, 1965; Pierce & Delbecq, 1977). Decentralization is argued to affect positively the initiation of innovation activities (Damanpour, 1991; Galbraith & Merrill, 1991; Miller, Droge, & Toulouse, 1988; Pierce & Delbecq, 1977) by increasing the feeling of involvement among organizational members (Pierce & Delbecq, 1977). Further, decentralization increases the efficiency of information processing by reducing vertical transfer of knowledge (Hull, 1988; Tsai, 2002) and speedier utilization of local knowledge (Siggelkow & Rivkin, 2006). While not strictly necessary, scholars (Tsai, 2002) have also associated centralization of decision making with strong bureaucratic controls which hampers sharing of information (Tsai, 2002). On the other hand, centralized authority has been positively linked with the implementation of innovation and hence potentially with the productivity of innovative efforts (Pierce & Delbecq, 1977). Galbraith & Merrill (1991), for instance, found that centralization did reduce R&D investments but positively affected the quality of innovations. This assertion, however, is not unchallenged. Damanpour's (1991) meta-study, for example, did not find support for the thesis that centralization affects different stages of innovation differently.

Similarly, formalization has also been argued to have different impacts on the initiation and implementation of innovations. In earlier theorizing of the effect of formalization, it was generally argued that greater formalization reduces the openness in an organization, adversely hurting the generation of ideas (Pierce & Delbecq, 1977) while the singleness of purpose enforced by formalization helps in productivity of innovation (Pierce & Delbecq, 1977). However, later arguments have emphasized the need of informal communication among organization members for the productivity of innovation efforts as well (Brown & Eisenhardt, 1997; Galbraith & Merrill, 1991; Hull, 1988; Tsai, 2002; Tsai & Ghoshal, 1998). Formalization is argued to hamper such informal interactions (Galbraith & Merrill, 1991) and thus adversely impact the productivity of innovation efforts. While some scholars (Tsai, 2002) have treated formalization as a subset of the concept of centralization, most scholars distinguish (accurately) between the two (Galbraith & Merrill, 1991; Jansen, Van den Bosch, & Volberda, 2005; Miller et al., 1988).

Empirical results on the effect of formalization on innovation are weaker than those for the effect of centralization on innovation (Galbraith & Merrill, 1991; Miller et al., 1988). In one study of organizational antecedents of absorptive capacity, Jansen, Van den Bosch and Volberda (2005) found that while formalization did not significantly impact the acquisition of external knowledge; it positively impacted the transformation and exploitation of external knowledge, providing support to the thesis that formalization affects different stages of innovation process differently. Other contingency factors such as environmental uncertainties (Damanpour, 1996), nature and scope of innovation (Damanpour, 1991), level of development of production processes (Collins et al., 1988) and the nature of knowledge (Galunic & Rodan, 1998; Szulanski, 1996; von Hippel, 1994) have been theorized to influence the relationship between organizational structure and innovation. Although some studies regarding adoption of new production processes such as Collins et al. (1988) provide some empirical evidence for the contingency arguments, this area of research in general needs greater empirical support.

Although the research mentioned above provides many insights into the impact of structure on innovation outcomes, it suffers from several empirical and theoretical constraints. The difficulty of getting organizational structure data on a large sample of organizations over time has implied that most of the studies in this literature are based on self-reported data from surveys and are cross-sectional in nature. Small sample sizes also restrict the ability to control for many of the other determinants of innovation, including industry effects. Another problem is the possibility of reverse causality. For instance, Miller et al. (1988) found that a firm's R&D intensity influenced its choice of structural parameters. This suggests a need for a longitudinal research design (Tsai, 2002).

A number of theoretical concerns also need to be accounted for in this literature. For instance, it is not clear that greater innovation efforts at lower levels of organization—as decentralization is supposed to encourage—are necessarily good for the overall innovativeness of the firm (Siggelkow & Rivkin, 2006). Similarly, decentralization may lead to monitoring through financial controls that may make managers risk-averse and reduce innovation (Hoskisson et al., 1991). This suggests that studies examining the impact of organizational structure on firm innovativeness also need to consider the impact of incentive structures (Galbraith & Merrill, 1991). Of course, in studying organizational structure, one should also consider informal structures such as inter-organizational social networks. We examine these in the context of organizational processes later as the two issues are related: organizational processes and systems lead to the development of informal structures such as intra-firm social networks.

More recently, other parameters of organizational structure are also being examined (Ethiraj & Levinthal, 2004; Siggelkow & Rivkin, 2006; von Hippel, 1994). Borrowing from the contingency theory of organization design (Thompson, 1967), scholars have studied the influence of partitioning of tasks on innovation (Siggelkow & Rivkin, 2006; Ethiraj & Levinthal, 2004). von Hippel (1994) argued that knowledge is sticky because it is tacit and task-specific. Given the level of stickiness, firms may partition the innovation tasks in a way that each organizational module draws on knowledge from only one location. However, while modularity may enhance innovation by facilitating specialization of search efforts and greater trials of recombining, it is important to get the partitioning right (Ethiraj & Levinthal, 2004; Yayavaram & Ahuja, Forthcoming). Indeed, Hoetker's (2006) study suggests that product architectures may determine organization structure in turn, raising again the specter of reverse causality.

Organizational structure not only affects the overall innovativeness of firms, but also affects the kinds of innovations created by a firm (Argyres & Silverman, 2004; Henderson & Clark, 1990; Toh, 2007). Henderson and Clark (1990) argued that firms were organized to suit certain product architectures. The organization of work creates information channels and institutes information filters which allow only a biased version of information to transfer between units. These channels and filters are largely tacit and hidden and consequently the bias is not apparent and difficult to correct. Information about architectural innovations, which require a reconfiguration of productive processes, is most likely to be filtered out because the filters and channels are specifically designed to suit a particular existing product architecture. Using an interesting research design, Toh (2007) finds that the organizational structure of firms affects the scope of their innovations and *vice versa*. Argyres and Silverman (2004) study the impact of organization of R&D activities on the kind of innovations generated by the firm. They argue and test the hypothesis that centralized R&D units create innovations that have broader impact. However, they found weak support for the hypothesis that centralized R&D units searched broadly. Overall, this stream of research suggests that organization of activities in a firm has a significant impact on both the rate and direction of innovation activities pursued by the firm.

Organizational processes. Research on the effects of organizational processes on innovation is much more disparate though its focus has largely been on the productivity of research efforts rather than on the incentives to innovate. Three broad sets of influences have been identified in this context: the role of social ties between organization members, the use of environmental scanning processes, and the role of innovation management practices. We examine each of these in turn.

One stream of research identifies the importance of social ties (Tsai, 2002; Tsai & Ghoshal, 1998; Szulansky, 1996; Jansen et al, 2005; Hansen, 1999) among units in facilitating knowledge transfer. Such knowledge transfer enables firms to recombine knowledge (Galunic & Rodan, 1998) and thereby increase innovations. The knowledge sharing also enables firms to make the innovation process more efficient (Hansen, 1999; Brown & Eisenhardt, 1997). Lahiri (2004) uses the context of multinational corporations to demonstrate the value of intra-organizational linkages in absorbing knowledge spillovers. Thus, creating social connections between organizational members helps both in generation and implementation of ideas. Scholars (Tsai, 2002) have also identified factors such as competition between units of firms as moderators of the effectiveness of social relations. Brown and Eisenhardt (1997) showed that certain firms instituted regular inter-departmental meetings to facilitate social exchange and the exchange of ideas. Jansen et al. (2005) argue that job-rotation can be one means of creating ties. Williams and Mitchell (2004) argue that organizational units serve as receptors of the environment and transmit the knowledge learnt from environment internally. Ties between the units created by internal transfer of executives serve as information channels which help complementary strengths in the organization to come together to act on the information. They, therefore, provide further evidence that creating inter-unit ties through job rotation helps innovation.

Establishing processes to probe the future (Brown & Eisenhardt, 1997; Gersick, 1994) and to scan the environment (Henderson & Cockburn, 1994) is also proposed to help innovations. Brown and Eisenhardt (1997) give examples of innovative firms that regularly scanned the future and created systematic processes of transitioning from present to future. Gersick (1994) identified the importance of time-paced changes where project teams probe the future at regular intervals rather than in response to events. Henderson and Cockburn (1994) find that firms that created systems that encouraged research personnel to engage in the broader scientific community were more productive. This process, coupled with cross-disciplinary communication and decentralized decision-making processes (such as by a governing committee), enhanced innovation in pharmaceutical firms (Henderson & Cockburn, 1994). These studies raise an important concern which is of fundamental importance in explaining inter-firm differences (Henderson & Cockburn, 1994): If such processes do lead to better productivity of innovation, why is it that all firms do not adopt these processes? However, this still remains an open question.

A third significant stream of research (Day, 1994; Tatikonda & Montoya-Weiss, 2001) identifies the processes that help product development projects succeed. This literature has identified support from upper management (Day, 1994; Dougherty & Hardy, 1996) and the role of champions in making projects successful. Project champions are organizational members that take ownership of the project and garner support and resources from the organization for the project. The support can arise from bottom rungs of the organizational hierarchy (Burgelman, 1983), leading to bottom–up championing or can come from the top down. Highly visible and disruptive projects, however, need top–down championing for success (Day, 1994). Dougherty and Hardy (1996) argue that champions may be beneficial for individual projects but for sustained innovativeness, the top management should create a mindset for innovation, make innovation meaningful for the entire firm and make innovation an important part of strategic conversation. Reflecting a similar focus, (Smith, Collins & Clark, 2005), in a survey based study of high technology firms, argued that organizational climate that promotes risk taking helps in innovation.

Summary. Studies that relate the organizational structure to innovation suggest a need for a multidimensional approach and a contingency framework (Damanpour, 1991, 1996). While certain features of organic structures such as decentralized control, lack of formalization and informal communication channels have been argued to be conducive to innovation (Pierce & Delbecq, 1977; Hage, 1999; Damanpour, 1991, 1996; Galbraith & Merrill, 1991), studies suggest that the effect of organizational characteristics on innovative output may depend on many contingent factors (Damanpour, 1991, 1996; Pierce & Delbecq, 1977; Collins et al., 1988) such as the stage of technological life cycle (Westerman et al., 2006), the kind of innovation (Damanpour, 1996), age of the firm (Sine, Mitsuhashi, & Kirsch, 2006), the nature of the industry the firm is in (Sine et al., 2006) and the stage of innovation (Pierce & Delbecq, 1977). For instance, structural features such as decentralization that induce generation of ideas and research efforts may not be best suited for the effective conversion of those research efforts into commercial quality innovations (Galbraith & Merrill, 1991).

The contingency framework referred to previously points out different and potentially complementary advantages of different organizations. While small, organic firms may be good at generating new ideas, large mechanistic firms may be better at converting those ideas into commercial high quality innovations (Puranam, Singh & Zollo, 2006). To the extent firms face difficulties in managing two different and opposing organizational setups, efficient generation of innovation may demand the existence of different firms (Gans et al., 2002).

Empirical research (Galbraith & Merrill, 1991; Damanpour, 1991) also suggests taking a more multi-dimensional approach in examining the relationship between innovation and organizational structure (Damanpour, 1991, 1996). Elements of organizational arrangement such as the structure and incentive systems may jointly affect innovative output; the effect of centralization on innovative output may differ based on the incentive and control systems used such as financial controls or strategic controls (Hoskisson & Hitt, 1988; Hoskisson et al., 1991). Hence, identification of interactions between the elements of organizational arrangements in influencing innovation efforts and productivity may lead to valuable insights.

Overall, these studies provide important insights towards understanding how the organization of activity affects innovation. However, perhaps what is as notable is what has not been studied (or studied rarely) so far in this area. Innovation is inherently a risky activity. This implies that for organization members to engage in it, the incentives should be appropriately structured.

Yet little research in the management domain has looked at the issue of incentive structures for innovation. The riskiness of innovation also draws attention to a second important omission. Innovation can be risky, not just for the innovator, but also for users or society at large. This implies that systems to generate and motivate innovative efforts need to be coupled with control systems that mitigate the risks from innovation. From financial services to pharmaceuticals, the dangers from innovation whose effects are not fully understood have become dramatically visible. Yet, we as a field have very little to say about why the organizations that generated these innovations either failed to foresee their consequences or lacked systems to prevent their generation. Either way, it highlights the importance of organizational structures and control systems in generating innovative efforts and output. Studying such structures and systems would appear to be a natural next step in this area. Finally, the important question raised by Henderson and Cockburn (1994) remains unanswered: why do large and persistent differences across firms in the way research is managed "given the apparently large pay-off to changing the organization and management of this crucial function" (1994, p. 79) exist? Answering this question is another important direction for future work.

3.2 Corporate Governance, Compensation, Incentive Structures

Relying on agency theory arguments, scholars (Galbraith & Merrill, 1991; Hill & Snell, 1988; Hoskisson, Hitt, Johnson, & Grossman, 2002; Kochhar & David, 1996; Porter, 1992; Zahra, 1996) have contended that corporate governance mechanisms and incentive structures of firms influence the risk appetite of managers and consequently the incentives to invest in innovation activities. Two basic premises dominate this literature. First, stockholders and managers differ in their risk preferences. While stockholders can diversify away idiosyncratic risk associated with any particular firm, managers' futures are tied to their firms and their rewards are adversely affected when risky ventures are not successful (Hill & Snell, 1988; Hoskisson et al., 2002). Hence, owners would want managers to take more risk than managers are willing to take. Second, investing in innovation is risky since the outcome is unpredictable. The two premises together suggest that managers are likely to be less willing to invest in innovation activities than owners would want them to.

Owners can rely upon two broad sets of mechanisms to address this basic problem: monitoring mechanisms that allow owners to better supervise managers and bonding mechanisms that reduce the incentive incompatibility by aligning managers' interests with those of shareholders. We discuss each of these in turn below. We largely concentrate on the effect of these mechanisms on the incentives of managers to invest in innovation. These mechanisms, especially monitoring mechanisms, can also be relevant in influencing the productivity of innovative effort by mitigating moral hazard in innovative activity. However, moral hazard is not unique to innovative activity and has been dealt with by agency scholars more generally. We therefore concern ourselves with the effects of bonding and monitoring mechanisms on innovative efforts.

Monitoring mechanisms such as the presence of outside directors (Hill & Snell, 1988), managerial control systems, and the degree of stockholder power (Hill & Snell, 1988; Kochhar & David, 1996; Porter, 1992; Zahra, 1996) affect managers' motivations to invest in innovation by exerting external pressure on them. However, the direction of influence is a matter of contention and depends on the preferences of the owners. Owners' preferences for investments in innovation may themselves be heterogeneous (Hoskisson et al., 2002; Kochhar & David, 1996) as stockholders can differ in their investment time horizon. On the one hand, scholars (Graves, 1988; Porter, 1992) argue that stockholders that diversify away the idiosyncratic risks associated with individual firms are interested only in short-term returns on investment. This forces a short-term focus on managers who therefore desist from investing in long-term projects which in turn adversely affects investments in innovation. On the other hand, scholars (Kochhar & David, 1996) have argued that large institutional stockholders, especially if they hold large blocks, can't divest the stock from their portfolio without adversely affecting stock price and consequently their returns. As a result, they use their power to voice their concerns and actively influence the managers of the firm to invest in long-term innovation projects.

Hoskisson et al. (2002) found that while certain institutional investors such as mutual funds have a short-term focus because the fund managers themselves are evaluated on short-term financial returns, other investors such as pension funds take a longer term view because pension funds are restricted from shuffling their portfolio and pension fund managers are rewarded on a salary basis. These studies together suggest that the first basic premise that owners want managers to invest more in innovation than the managers would like may not be uniformly true; the overall influence of owners on innovation may depend on the mix of shareholders and their investment objectives. They however do raise an additional puzzle—why would efficient markets not price in good innovation strategies appropriately? In other words, if the "right" decision is to invest in long-term innovation, then firms making that decision correctly should see that decision reflected in their stock prices instantaneously. If so, then why would the interests of short-term and long-term investors differ?

Research on bonding mechanisms such as incentive schemes underline the need to consider the time-horizon of investors along with the form of the compensation. Scholars (Galbraith & Merrill, 1991) have found that short-term cash rewards reduce risk-taking, while rewards such as stock options, which are longer-term and confer ownership on the manager, reduce the risk-aversion of managers. Relatedly, in a series of studies, Hoskisson, Hitt and colleagues (Hoskisson & Hitt, 1988; Hoskisson et al., 1991) found evidence for the proposition that evaluating and rewarding managers on the basis of financial returns adversely affects the motivation to innovate, but evaluating them on subjective criteria such as the quality of strategy adopted encourage innovation. These studies show that evaluating managers on long-term performance and giving them more ownership of the firm is effective in promoting innovation investments within a firm.

The discussion thus far suggests that there may be a case for qualifying the first premise identified earlier in this section, which is that managers are likely to invest less in innovations than the owners would like them to invest. Depending upon the mix of investor type (short-term versus long-term oriented) this may or may not be true. However more work is required to clarify why the interests of short-term and long-term investors would differ in this context. The second premise, that innovation is a risky enterprise, seems more uncontroversial. However, we should compare the risk of investing in innovation with the risk associated with not investing in innovation (McEachern & Romeo, 1978) which may vary based on industry conditions such as the level of technological change in the industry. In high-tech industries for example, not investing in innovation may be more risky from the point of view of managers because investing in innovations may be an institutional norm in those industries. Further, in such industries, the compensation of managers may itself be contingent on the investments they make in innovation. For instance, Balkin, Markman and Gomez-Mejia (2000) found that in high technology industries, the amount of long and short-term pay of CEOs could be predicted by the amount of R&D spending and patent activity in their firms. Hence, the bias of managers in those industries may be towards over-investing rather than under-investing in innovation. If that is the case, the direction of influence of corporate governance mechanisms and incentive-alignment schemes may differ from industry to industry based on the norms of that industry. While some evidence (Zahra, 1996) does suggest that industry conditions moderate the influence of corporate governance mechanisms on innovation, studying how industry conditions may alter the impact of these mechanisms on innovativeness of firms may be a promising area of future research.

3.3 Background of Managers

Introduction. So far, we have examined the environmental and organizational determinants of innovation. However, scholars following the upper-echelons approach (Hambrick & Mason, 1984) suggest that the characteristics of the top management team also influence the efforts that a firm puts into any strategic activity (Bantel & Jackson, 1989; Hambrick & Mason, 1984). The top managers, being human, are influenced by psychological and social biases in their decision making (Hambrick & Mason, 1984; Tversky & Kahneman, 1974). The factors that the managers deem important in decision making are influenced by their cognitive maps and mental filters (Tripsas & Gavetti, 2000). These mental biases, maps and filters become even more relevant when the decisions are about efforts whose outcomes are uncertain (Hambrick, Cho, & Chen, 1996). Since innovation efforts have uncertain outcomes, the mental outlook of decision makers should have a significant bearing on innovation decisions (Wu, Levitas, & Priem, 2005). Therefore, it is important to study top managers' cognitive make-up to get an understanding of motivations to innovate.

This literature assumes that the mental maps, biases and filters of top managers can be inferred from looking at the demographic characteristics of the managers such as their age and the past background of managers such as educational and functional background (Hambrick & Mason, 1984). Further, since top management takes decisions collectively, it is also important to examine the role of the composition of the top management team in innovation decisions (Hambrick et al., 1996; Hambrick & Mason, 1984). At an individual level, scholars (Bantel & Jackson, 1989; Khan & Manopichetwattana, 1989) have most commonly looked at how the characteristics of managers such as age, organizational tenure and educational background influence innovation decisions. The most studied characteristic of the top management team as a whole is the level of diversity in the team—diversity in functional backgrounds, level of education, age and tenure in the top management team (Bantel & Jackson, 1989; Hambrick et al., 1996).

Individual characteristics. There are two reasons to expect the age of top managers to affect the motivations to invest in innovation. The first argument relies on findings in psychology which suggest that aging causes certain mental abilities such as learning and memory to decrease (Bantel & Jackson, 1989; Burke & Light, 1981). Further, younger managers are more likely to be trained in new technology (Bantel & Jackson, 1989). Since innovation involves creation of new ideas and combining existing elements in new ways (Schumpeter, 1942), decreasing mental abilities make older managers less able to invest in innovations. The second argument suggests that older managers are also less willing to invest in innovations. Older managers have a negative attitude towards taking risks (Bantel & Jackson, 1989; Vroom & Pahl, 1971) compared to younger managers. Since older managers are nearer the end of their careers, they are more worried about the short-term negative consequences of failure and so do not invest in projects with a long-term pay-off (Wu et al., 2005). Both arguments suggest that the motivations to invest in innovation decrease with age.

The above arguments, however, contradict the view that managers learn with experience (Wu et al., 2005; Nelson & Winter, 1982). By virtue of longer tenure in an industry, older managers may have a broader view of the industry. Over time they may have developed a significant network of relationships in the industry (Wu et al., 2005, Hambrick & Mason, 1984) which may increase the availability of resources that can be used for innovation. Learning from past successes and mistakes may make the older managers more informed about the success of certain search paths (Wu et al., 2005). This may, in turn, motivate them to invest more heavily in innovations.

Research in the upper-echelons tradition does not conclusively show any impact of age of managers on innovation. The contradictory arguments identified above suggest that the influence of age on motivation to innovate may be contingent on other variables. For instance, it may be the case that the age of managers may influence the direction of innovative activity more than the volume. Older managers may be more interested in incremental and process innovations which are less risky and shorter term. Younger managers may, on the other hand, have greater incentives to invest in radical innovations which have a greater impact in the longer term. Unfortunately, this possibility has not yet been tested.

The organizational tenure of managers also affects their motivations to invest in innovation. While organizational tenure is often correlated with age (Bantel & Jackson, 1989), organizational tenure differs subtly from age in how it affects the motivations to innovate. Scholars (Bantel & Jackson, 1989; Staw & Ross, 1978) argue that organizational tenure leads managers to have psychological commitment to organizational processes and organizational values. This commitment leads tenured managers to resist change and therefore discourage innovation. This reasoning suggests that a longer tenure reduces the willingness to innovate (Bantel & Jackson, 1989). However, tests of a linear relationship between tenure and innovativeness have not revealed such a relationship (Bantel & Jackson, 1989).

When we consider the effect of tenure on the ability of managers to implement a change in the organization, we get a different picture. Top managers become more effective as their tenure in the organizations increases (Penrose, 1959; Nelson & Winter, 1982). They learn from experiences and build internal and external networks that help them establish control over the organization. The increased knowledge and power enables the long tenured managers to be more capable in effecting change in the organization and in directing the firm's resources towards risky projects. This point of view, therefore, suggests that top managers of firms are more able to increase their firm's innovation efforts. This argument also makes the case for organizational tenure having a positive influence on the productivity of innovation efforts. Managers with greater organizational tenure may be more capable of "getting things done" within the organization resulting in a more productive use of resources devoted to innovation.

The two countervailing forces discussed previously suggest an inverted-U relationship between the innovative output of firms and the average tenure of their top managers. Wu et al. (2005), while studying this relationship in the context of pharmaceutical firms, found that that the innovativeness of firms and organizational tenure of CEOs indeed have the inverted-U relationship. Further, they found that shorter tenured managers are more innovative in technologically dynamic industries while longer tenured managers are more innovative in less dynamic industries. This finding suggests that just like age, organizational tenure may also affect the direction and productivity of innovative activity more than its volume.

Scholars (Bantel & Jackson, 1989; Khan & Manopichetwattana, 1989) have found that the average level of education of top managers also affects the motivation to innovate. Increases in the education levels of managers increase their cognitive ability to understand and initiate new solutions (Bantel & Jackson, 1989). This increased ability may also make them have more favorable attitudes towards innovation and motivate them to invest more in innovation.

Top management team composition. Scholars (Bantel & Jackson, 1989; Hambrick et al., 1996) have argued that heterogeneity in the top management team (along dimensions such as functional background, education and organizational tenure), is a significant factor in determining the innovativeness of a firm. Heterogeneity is argued to promote innovativeness because it helps firms to account for a larger set of problems and solutions (Bantel & Jackson, 1989). The diversity of opinions inherent in a heterogeneous team ensures a more exhaustive analysis of problems and prevents group think (Hambrick et al., 1996). Simultaneous consideration of diverse points of view leads to more novel ideas (Hambrick et al, 1996). However, heterogeneity in team composition is argued to adversely affect the productivity of innovative efforts. Differences of opinions may lead to conflict among team members (Bantel & Jackson, 1989; Hambrick et al., 1996), the resolution of which may waste time and managerial resources (Hambrick et al., 1996). Thus, while team heterogeneity may help in the generation of novel ideas, it may hamper the time taken to come to a decision and it may also hinder the implementation of such ideas. Hambrick et al's (1996) study corroborates the above predictions. They find, in the context of airlines, that firms with diverse top management teams were more proactive in taking new competitive actions while they were less likely to react to competitive moves of others. Further, the moves generated by diverse teams were more impactful. However, diverse teams were slower in generating and implementing both new actions as well as reactions. Interestingly, Bantel and Jackson (1989), in their study of innovations in the banking sector, found that heterogeneity in the functional background of managers positively impacted administrative innovations but had no impact on technical innovations. Why this should be the case is still unexplored.

3.4 Organizational Search Processes

In an attempt to pry open the black box that is the innovation production function, researchers have also modeled the process by which new inventions emerge. Many of these models represent innovation as the result of an organizational search or learning process (Levinthal & March, 1993; March, 1991; Miner & Mezias, 1996). Several different types of search mechanics have been outlined in these models including recombinatory, cognitive and experiential search (Fleming, 2001; Fleming & Sorenson, 2004; Gavetti & Levinthal, 2000). The constructs of local versus distant search are central to these models. Building upon the pioneering work of Nelson and Winter (1982), Cyert and March (1963) and March (1991), scholars have tried to understand the nature and direction of exploratory activity conducted by firms and its implications for innovation output (see Gupta, Smith & Shalley, 2006). In an innovative paper on the petrochemicals industry, Helfat (1994) established that firms were far more likely to invest in the neighborhood of their existing technologies. Other scholars (Almeida, 1996; Stuart & Podolny, 1996) have also confirmed this behavioral tendency towards local search i.e. of organizations to search in the neighborhood of their existing activities rather than at some distance from them.

Recombinatory search models are the implicit underlay for a large body of work on innovation (the concept of recombination as a source for new inventions in fact dates back to Schumpeter, if not earlier). The basic premise of these models is that new inventions emerge from the recombination or "mixing and matching" of existing elements of knowledge (Grant, 1996; Kogut & Zander, 1992). According to this model, firms (or inventors) have access to knowledge elements (their knowledge base) and they generate different combinations of knowledge some of which turn out to be useful. Thus, innovation output can be increased by enhancing the recombinatory set, or set of knowledge elements that can be accessed by a firm.

This basic model has been enhanced or conditioned by researchers whose work has highlighted various implications and assumptions of the model. For instance, Henderson and Clark's (1990) analysis of architectural change suggests that modeling the organization as a unitary knowledge base may be an oversimplification. Knowledge within an organization may actually be tightly circumscribed by organizational sub-unit boundaries, and recombining across those boundaries may be prohibitively difficult. Similarly, Rosenkopf and Nerkar (2001) highlight another set of partitions within a knowledge base, suggesting that recombination can occur in several distinct ways once one recognizes that in the recombinatory process, firms can access knowledge from within their own organizations or from other organizations and from within the same technology or from other technologies. They argue (and demonstrate) that crossing either boundary (organizational or technological) in recombinatory search has implications for innovative output.

Ahuja and Katila (2001) look at the issue of organizational boundaries and draw attention to the mechanisms for enhancing the knowledge available for recombination by examining the technological acquisitions of firms.

In their knowledge-based framing, mergers of firms can be regarded as a union of the knowledge bases of those firms, making available an enhanced recombinatory set. They argue and find support for the arguments that the innovative output generated post-merger is likely to be related to the size of the merged knowledge bases and to the degree of overlap between them. Specifically merging knowledge bases with moderate degrees of overlap provides greater innovation impact relative to merging high or low overlap knowledge bases. Puranam et al. (2006) push this argument still further making a distinction between two potential objectives of technological mergers—using the acquired firm's knowledge as an input into their own knowledge versus using the acquired firm as an independent source of knowledge and invention. They show that there is a fundamental conflict between these objectives. Tight integration of the two knowledge bases into one can help the firm use the acquired knowledge elements in their own innovations but limits the ability of the firm to use the acquired knowledge base as a distinct source of innovation. Paruchuri, Nerkar and Hambrick (2006) also provide support for a post-integration loss in acquisitions demonstrating that the knowledge networks of scientists may be affected by the post-merger integration leading to a decline in the scientists' productivity. From a recombinatory perspective this suggests that the integration that is used to enhance the post-merger recombinatory set for a firm is far from costless in terms of innovation outcomes.

Other explorations of this basic model have extended it in two broad directions—elaboration of the search process and its implications and antecedents, and enhanced understanding of the underlying construct of the organizational knowledge base. Katila and Ahuja (2002) draw attention to the possibility that there may be two very distinct dimensions of recombinatory search. Search can entail the exploration and use of new elements of knowledge (i.e. elements hitherto unused by the firm), a dimension they call search breadth, but it could also entail exploration and repeated use of knowledge elements that the firm already has, a dimension they call search depth, or some combination of the two. While search breadth could provide new contexts and applications for inventions, search depth could provide a richer understanding of a given context. They demonstrate that being able to manage search across both dimensions is associated with the frequency of new product introductions in the robotics industry. Laursen and Salter (2006) use an open innovation perspective to demonstrate that in a much broader sample of UK manufacturing firms, searching both broadly and deeply is related to superior performance.

Katila (2002) and Nerkar (2003) draw attention to the temporal aspect of this search process suggesting that the knowledge base is a dynamic entity and that elements of knowledge vary in their salience and importance in the recombinatory process over time (as demonstrated by the revealed preferences of inventors using citation data). Benner (2002) and Benner and Tushman (2003) show that the adoption of variance reduction practices in organizations shifts the focus of innovation towards exploitative innovation rather than exploratory. They demonstrate that the adoption of ISO quality standards leads to the generation of relatively more incremental innovations.

In a similar vein, Ahuja and Lampert (2001) use the search framing to inquire into the antecedents of breakthrough inventions in large corporations. They locate the oft-argued weakness of large firms in generating breakthrough inventions in the rational processes of these organizations that may have unintended consequences. Specifically, they argue that to deliver reliable products to their customers and maintain their reputation for stability and solidity large established firms need tried and tested processes that they have significant expertise with and strong bureaucratic controls. These tendencies (they call them the maturity trap, familiarity trap and propinquity trap) however, while being rational in terms of helping organizations meet their desired goals of being reliable producers and suppliers, also limit their ability to generate breakthrough inventions. They go on to show that firms that are able to avoid these concerns through exposure to new, emerging and pioneering technologies are able to generate more significant inventions. Other scholars have pushed this recombinant perspective to include search beyond the technology dimension arguing that it is a combination of both technological and market capabilities that permit the maximal success (Mitchell & Singh, 1996; Nerkar & Roberts, 2004). In a study that uses success of new products as the outcome variable Nerkar and Roberts (2004) show that marketing and technology experience combine interactively to explain new product success.

In a paper that focuses attention on the knowledge-base aspect of search processes, Yayavaram and Ahuja (2008) argue that the recombinant process argumentation suffers from a basic limitation. Recombinant processes that work through enumeration of invention possibilities must fairly quickly hit the wall of combinatorial complexity—even with small numbers of elements in a knowledge base, the total number of combinations to be evaluated is simply too many. They suggest that one way of reconciling the recombinant perspective with this computational complexity roadblock is to consider the possibility that firms couple elements (treat multiple elements as one) in the search process thus reducing the number of combinations to be evaluated. Of course, in the presence of uncertainty and lack of perfect knowledge of what elements should be ideally combined, coupling raises the possibility that firms differ not in the knowledge elements that they have but in what elements they couple with each other and the resultant coupling patterns they use. They suggest that knowledge bases whose coupling patterns can be characterized as nearly decomposable (as opposed to modular or integrated) lead to the generation of more useful inventions.

Although this brief and clearly inadequate review shows that the recombinant search perspective has helped to provide one theoretical lens for understanding how innovation gets generated it also draws attention to the great gaps in our knowledge in this arena. First, there exists relatively little systematic empirical evidence (as opposed to anecdotal) that recombination is in fact a leading source of innovation. Few, if any studies actually look inside the firm to confirm that recombination is being used at all in fact. Most of the work has been conducted with the scholar at some distance, using archival patent and citation data, to infer or refute hypotheses. From another angle, few studies have examined the costs of recombination as a determinant of innovation practices and outcomes. If we assume that recombination is indeed an important mechanism of innovation, the ability to enumerate and evaluate enumerated ideas are central to coming up with good inventions. Yet, these abilities are going to be dependent on the cost of recombinant experimentation. Little work has addressed this issue. More generally, exploration of the mechanisms of innovation is limited, as work on mechanisms other than recombination is even more limited than work on recombination. Understanding the process by which firms generate new ideas and inventions remains a fecund ground in this arena (though see the creativity literature and work by scholars such as Teresa Amabile, which is not covered in this review).

4. Institutional Influences

In addition to the industry, firm and intra-organizational attributes identified previously, institutional environments are a key determinant of innovation efforts and the productivity of those efforts. The role of institutions in the context of innovation has been widely explored by economists and forthcoming surveys by Arora and Gambardella, and Wes Cohen, should provide a very recent update of this literature. Accordingly, in this survey we only touch upon a few aspects of this topic here, specifically those that have greater salience within the management literature. Studying the role of science is important because its interaction with corporate investment decisions affects both the incentives to conduct R&D and the productivity of the conducted R&D. The second key component of the institutional environment that has significant bearing on corporate research investments and research productivity is the set of appropriability conditions in the industry which determine how much the firm can hope to get as return from its innovation investments. We examine these in turn.

4.1 Science and Innovation

Basic arguments. Progress in science and technology motivates firms to invest in R&D activity through both direct and indirect mechanisms. Scientific progress can directly influence the motivation to innovate by providing knowledge inputs to the innovation process. The availability of complementary knowledge encourages investments in commercialization and application of that knowledge (Dosi, 1982). Science can also influence innovation efforts indirectly. Scientific progress motivates a firm to invest in R&D by increasing the need for prior knowledge necessary to profit from the progress in science. Knowledge generated by scientific progress usually cannot be applied directly (Cohen & Levinthal, 1990) but needs to be understood, modified and assimilated by a firm to produce commercializable products. Cohen and Levinthal (1990) call this ability absorptive capacity. They argue that this capacity can't be attained easily as firms need sustained investments in R&D to understand and evaluate external knowledge. Thus, scientific progress motivates the firm to invest in research indirectly by increasing the need for absorptive capacity which can only be built by sustained investments into research activities.

Scientific progress can also make the innovation process more productive by providing a heuristic guide to the search process that increases the likelihood of success of research (Cohen, 1995; Nelson & Winter, 1982). Research activity in firms can be modeled as a search for solutions in the knowledge domain (Ahuja & Katila, 2004; Fleming, 2001; Rosenkopf & Nerkar, 2001). Scientific progress sheds light on the likelihood of success along certain search paths. By discovering new cause–effect relationships, scientific progress can identify which paths are dead-ends and which paths are more likely to succeed. The firm can use this information to narrow its search. Further, scientific progress can also open up new search-paths for the firms. For instance, science might identify potential new directions of innovation by highlighting new cause effect relationships or by providing recombinant fodder for new inventions (Ahuja & Katila, 2004; Fleming, 2001; Fleming & Sorenson, 2004).

Challenges to the basic argument. Although there is support for the idea of science as an input to technology (Ahuja & Katila, 2004; Tijssen, 2002) research suggests that the relationship between science and innovation is actually far more complex. Gittelman and Kogut (2003) highlight that the pursuit of good science does not naturally coincide with the pursuit of valuable innovations. Science and the pursuit of commercially valuable innovation represent very different institutional systems and the criteria by which good science is assessed differ from the selection logic applied to industrial innovations (Gittelman & Kogut, 2003). The idea that science and industrial innovation come from different and not necessarily congruent institutional contexts has implications for the cost effectiveness of innovation too. Stern (2004) uses an innovative research design to find that scientists, in fact, pay to be scientists. Allowing corporate scientists to publish and be active in science may have both productivity and wage reduction benefits for corporations. This makes the corporate investment task quite complex. Investing in science may be important for the corporation for several reasons but it does not necessarily enhance innovation in the most valuable directions.

Future Directions. Researchers have also examined the role of universities as one aspect of the science–industry interface. The passage of the Bayh-Dole act in 1980 has been a land-mark in this context and several studies have examined the patenting behavior of universities evaluating questions such as whether the rate and quality of university invention has been enhanced since the passage of the Bayh-Dole Act (Mowery, Sampat, & Ziedonis, 2002; Sampat, 2006). Although empirical work in this area is expanding, the final effects of Bayh-Dole are still unclear (Sampat, 2006). Indeed, presenting a theoretical framework that makes directional predictions about the effects of Bayh-Dole on rate and quality of patenting would be a nice supplement to the existing empirical literature. More generally, Bayh-Dole raises an important question: what does conferring intellectual property rights (which to some extent introduce restrictions on the flow of knowledge) on institutions whose primary agenda includes broad dissemination of knowledge imply? Is there a possibility that science is becoming more privatized, such that commercial considerations determine the degree and conditions of knowledge sharing rather than academic norms of knowledge accumulation? If so, what does this imply for (a) scale economies in research; and (b) for the division of scientific labor between the public and private sectors and within the private sector, between large and small firms? Identifying and exploring the multiple dimensions of this question is an important task for future research in the area.

As the previous arguments suggest, the relationship between science and innovation is quite nuanced—institutional variations between science and innovation necessitate care before assuming that increasing exposure of organizational scientists to science is always a good idea. Further, while this research suggests that inputs from science may decrease the cost of research, the implications of such a reduction remain to be clarified. For instance, does such a reduction in search costs cause an expansion in the research efforts of incumbents, or does it also, under conditions to be identified, reduce the minimum efficient scale of research activity, thus prompting the entry of many more firms into the research space. Clearly this distinction is important because the first prediction suggests just an increase in the scale of existing efforts, but the second can lead to increases in the diversity of research efforts. Further, what firm characteristics are best aligned with taking advantage of public science is unclear. Does public science expand the research opportunity set of all firms in the same way? If not, under what conditions will given sets of firms be advantaged? For instance, Laursen and Salter (2004) draw attention to the fact that not all firms seek university research inputs and that there are systematic patterns in the use of university knowledge by firms.

Understanding the implications of this is important from both policy and strategy perspectives.

4.2 Appropriability Conditions and Innovation

Basic argument. Appropriability conditions refer to the environmental factors, apart from firm and market structure, that enable an innovator to capture the rents of innovation (Teece, 1986) by creating barriers to imitation by competitors. While a number of mechanisms such as trade secrets and complementary assets (Encaoua et al. 2006; Gallini, 2002; Teece, 1986) have been argued to enable an innovator to appropriate the value of the innovation, the most commonly studied and debated appropriability factor in the context of innovation is the legal protection provided by the patent regime of the country. Many excellent reviews (Encaoua et al., 2006; Gallini, 2002) have been written on the influence of patent regime on innovations. We refer the reader to those for a more detailed analysis of the problem. Here, we provide a broad overview of the major debates about the role of patenting in innovation.

The strengthening of the patent regime in the last few decades (Encaoua et al., 2006; Gallini, 2002) is a result of the belief that protections from imitation granted to innovators provide the innovators with incentives to innovate. The incentive effect of a patent regime relies primarily on assumptions about unique characteristics of knowledge: knowledge can be costlessly imitated and is difficult to protect from imitation (Encaoua et al., 2006; Arrow, 1962). Once an innovation is created, others can imitate it with lesser investment than the original innovator and therefore increase the competition for the innovator (Encaoua et al., 2006). Increased competition can prevent the innovator from recuperating the initial invention costs (Schumpeter, 1942). This reduces the incentives for investing in innovation. A strong patent protection regime prevents imitation by competitors and thereby affords the innovator a chance to recover the investments made into innovation. Hence, it creates incentives to innovate.

Challenges to the basic argument. The basic proposition that strong patent regimes spur innovation has been challenged on many fronts. First, many scholars, especially evolutionary economists (Cohen & Levinthal, 1990; Dosi, 1982; Nelson & Winter, 1982) have argued against the idea that knowledge once created, can be easily appropriated by imitators. They point out that providing patent protection may not be necessary to stimulate innovation if imitation is costly (Encaoua et al, 2006), which, they argue, is true most of the time.

Second, scholars such as Bessen and Maskin (2000) have challenged the idea that imitation of innovation always creates disincentives to invest in innovation. Attempting to explain why certain industries such as the software industry were more innovative under weak patent regimes, they argue that when innovation is both sequential and complementary, imitation may actually "spur innovation". This is because when innovation is sequential and complementary, competitors may build on the original innovation by pursuing different lines of research. These varied approaches may yield valuable ideas not available to the original innovators. In a subsequent time period, the original innovators may benefit from the new ideas—which they otherwise would not have obtained—and generate new innovations. This increases the overall pace of innovation. Thus, imitation may spur innovation while prevention of imitation through a strong patent regime may hurt it if the innovations are sequential and complementary.

Third, empirical surveys such as the Yale survey (1983) and the Carnegie Mellon survey (1994) demonstrated that in many sectors, legal protection mechanisms such as patents were not the preferred mode of preventing imitation (Encaoua et al., 2006). Rather, other market-based mechanisms such as trade secrecy and first mover advantages were preferred (Encaoua et al., 2006). These arguments suggest that the efficacy of a patent regime in motivating firms to invest in innovation differs across industries and depends on a number of market and technology characteristics (Gallini & Scotchmer, 2002). This prediction has been verified empirically. Mansfield (1986), for example, using a survey and interview approach, estimated the extent to which a sample of US manufacturing firms across industries would have reduced innovation in the absence of patent protection. He found that while in certain industries such as pharmaceuticals and chemicals, patent protection was essential for the development of 30% or more of the inventions, the percentage was markedly lower in other industries such as office equipment or textiles.

Qualifications to the argument. The relationship between the motivations to innovate and the intellectual property rights regime also depends on certain dimensions of the patent policy such as the stringency of patentability requirements (Encaoua et al., 2006; Hunt, 1999). The patentability requirement refers to the threshold an innovation has to cross before it can be granted a patent. Raising the threshold level has two countervailing effects. On the one hand, innovation efforts are reduced because the innovation has a greater chance of not receiving patent protection (Encaoua et al., 2006). On the other hand, the patent lasts for a longer time because generating an innovation which crosses the threshold and replaces the original innovation is more difficult (Encaoua et al., 2006). Further, a bigger innovation—one that crosses the threshold—is likely to yield better returns. This positive effect increases the incentives to innovate. Hunt (1999) shows that as a result of these countervailing forces, the rate of innovation has an inverted-U-shaped relationship with patentability requirements. Many studies have similarly studied the effect of various dimensions of patent regime such as length and breadth of patents on the rate of innovation (Gallini, 1992; O'Donoghue, 1998). Scholars have also studied how the kind of innovation process (O'Donoghue, 1998), isolated or sequential, and technological dynamism of the industry (Hunt, 1999) affect the characteristics of the optimal patent regime. Interested readers are referred to articles by Gallini (2002) and Encaoua et al. (2006).

Strategic implications. The stringency of the patent regime has strategic implications for firms. Patents, while conferring local monopolies also entail disclosure (Encaoua et al., 2006; Gans et al., 2002). These disclosure requirements suggest that patents can also be considered as codifications of knowledge or blueprints (Encaoua et al., 2006; Gallini, 2002). This codification may facilitate internal exploitation of knowledge but may also lead to its broader diffusion (Encaoua et al., 2006; Gallini, 2002). This has both positive and negative implications for firms.

Stronger patents, both by codifying knowledge and by mitigating expropriation threats, may encourage technology transfers (Arora and Merges, 2004) and promote division of labor in innovation (Arora & Gambardella, 1994a, 2008; Gallini 2002). The Bayh-Dole act, for instance, by allowing universities to retain their patent rights, facilitates technology transfer from universities to industry (Jensen & Thursby, 2001). By creating a market for technology, patents can provide a bigger market to innovators because innovators need not make complementary investments in marketing the innovation in order to reap the benefits of innovating (Gilbert, 2006). This provides an additional fillip to investments in innovation.

These benefits notwithstanding, a strong patent regime also imposes significant costs. First, a strong patent regime may discourage and prevent follow-on inventions (Nelson 1959, 2006; Bessen & Maskin 2002), which may slow down the overall rate of technical change. A strong patent regime which grants broad patents may also discourage innovation because of the fear of infringing on prior patents (Gallini 2002; Nelson 2006). Lerner (1995) showed that firms with high litigation costs discourage firms from research in areas that are occupied by other firms. Second, a strong patent regime may reduce the variety of search paths and prevent cross-pollination of ideas (Nelson, 2006), which may reduce the quality of innovations. Third, a strong patent regime may also provide distorted incentives which may lead to diversion of resources from productive activities to unproductive ones such as litigation (Gallini, 2002). For instance, Hall and Ziedonis (2001) found that firms in the semiconductor industry indulged in strategic patenting in order to obtain bargaining chips in subsequent litigation.

Future Directions. In conclusion, we can see that the relationship between the strength of the patent regime and the rate and direction of innovation is complex. As the list of positives and negatives of a strong patent regime suggests, appropriability conditions create a significant set of trade-offs for firms to manage and/or exploit. An interesting but somewhat under-explored strand of the literature is to consider how firms address the benefits and costs of given appropriability regimes. To the extent that firms are strategic players, one would expect that firm strategies would try to maximize the benefits from an appropriability regime while minimizing its profit-reducing effects. For instance, the double-edged sword of patenting suggests that firms that obtain the benefit of the monopoly conveyed by a patent must also deal with the cost imposed by patenting, enabling disclosure. Other things being equal, firms would be trying to maximize the monopoly effect while minimizing the disclosure. Relatively little work, however, has examined how firms strategize in this context. In a paper that draws upon the cumulative or sequential invention ideas and makes a distinction between primary appropriability (the firm's ability to profit from a given invention through products or licensing) and generative appropriability (the firm's ability to create many of the follow through inventions that build on a given invention), Ahuja (2008) examines how firms may develop strategies to limit the negative effects of disclosure while maximizing the benefits from patenting. In another study on the same theme of strategizing *vis-à-vis* the institutional structure, Polidoro (2006) highlights how firms may use one institution (science) to influence another institution (the FDA in his context) to accomplish strategic ends, such as shortening the time period for a pharmaceutical drug to be approved. These papers, however, just scratch the surface of this vast topic and how firms strategize using the characteristics of a given appropriability regime remains an open area for further investigation.

5. Concluding Remarks

We began this survey by suggesting that the basic question of understanding variation in innovation across firms could be decomposed into two components, the understanding of variations in innovative efforts and innovative outputs, respectively. Thereafter our strategy was to consider these two constructs as the outcomes in the research production function and the innovation production function respectively and identify the various arguments to these functions. In addition to helping us structure and organize the literature in a way that both economists and management scholars may relate to it, this exercise also served to highlight the key findings and limitations in each area and sub-area. This exercise also draws our attention to several broader issues that we summarize here.

First, the exercise establishes that scholars have had extraordinary success in identifying additional determinants of innovation beyond the size and market structure arguments that were the staple of this literature for a long time. Although the Schumpeterian hypotheses relating firm size and market structure to innovation have gathered the largest mind-share in the past, this rich assembly of identified influences, and the weak theoretical base for the original Schumpeterian claims suggests that perhaps the future of innovation research lies in building greater depth in our understanding of these multiple influences rather than developing more studies testing the links between firm size and market structure and innovation. In other words, "Moving Beyond Schumpeter" should not just be the title of this survey but also the motto for research in this area going forward.

A second noteworthy aspect highlighted by this survey is that, at the broadest level, there has been a difference in relative focus between economists and management scholars with the efforts of the former focusing more on understanding the determinants of innovative efforts relative to innovative outcomes and the latter devoting more of their energy to the determinants of innovative output, or the productivity of research efforts. This division of labor appears consistent with the emphasis on incentives in the economics literature and the emphasis on capabilities in the management literature. It also appears to have been a successful strategy as it has led to the exploration of a broad terrain with a variety of techniques. However, this survey raises the possibility that going forward there may be cross pollination benefits to be obtained as researchers in both domains swap problems and tool kits.

A third implication emerges from our observation that research has identified many more arguments to the innovation production function including several dimensions of organizational structure and governance and incentive systems, the staffing of innovation projects, the search process of the organization, and so on. However, what is worth noting here is that this research seems to suggest that these factors not only affect the quantum of innovation output, they may also affect its quality (radical versus incremental), direction (towards components or systems) and type (product versus process). Thus, the very representation of innovation as the output of a production function entails a simplification that may conceal as much as it reveals. Weaving these various dimensions of innovation into a bigger theoretical structure is an important later task that remains to be done. Over the next decade, as research fills out these gaps, this task could be accomplished.

On a related theme, we note that while research has identified many arguments to these two functions, it has been unevenly distributed across these arguments. For instance, the role of alliances and networks in innovation has been investigated extensively (and intensively). Yet, relatively little work has addressed issues such as supplier innovation and complementor innovation. Similarly, while recombinant search has been examined in some depth, alternate mechanisms of innovation have received lesser attention. Focusing more attention on the under-explored areas may provide an opportunity of making greater theoretical and empirical impact.

A fourth broad issue that needs to be addressed in this context is that while research has made a plausible case for many of these influences to be considered as arguments to the innovation production function (and in some cases to the research production function), their effects are in general not definitively established. This is so for at least two reasons. First, for many of these influences research has often provided conflicting effects. Second, even where the results are consistent across studies the problem of establishing causality remains. Endogeneity of the key regressors is an unfortunate problem that bedevils much of the work on innovation. Satisfactory solutions to establish causality demand instruments that allow identification of the true effects. Unfortunately, such instruments are extremely hard to find and without them the best one can do is accept these findings as stylized empirical facts. Innovative research designs and the use of contexts that permit causal identification rank high on the list of empirical desiderata in this area.

Finally, although in this review we have tried to identify the key features of empirical work in the area, as we go along there remains room for a few big picture takeaways. Possibly the dominant theme from an empirical perspective has been the use of patent data. The strengths and weaknesses of these are well known and reported elsewhere, so for the most part we will not detail them here. Patent data has proven to be an extremely fecund source for enhancing our understanding of innovation. However, to paraphrase Herb Simon, the wealth of information on patents has led to a poverty of attention to other forms and measures of innovation. Some of the most obvious areas of omission include the analysis of new products, the mapping of patents to products, distinctions between product and process innovation, and radical versus incremental innovations, and the generation processes for each, and identifying the sources of innovation in services and how that might differ from innovation in products. The issue here is not that there is no work in these areas but rather that, compared with what we have learnt about patents, we know relatively less about these areas. In this review, we have chosen to not explore these various topics for two reasons. First, there is simply a length issue—this paper is already much longer than we would like. Second, from the perspective of a review that seeks to summarize the learning across studies, the far fewer studies on these topics suggests that it might be useful to wait for a later survey to cover the issue. With this call for expanding research to other variables and data sources we conclude this survey.

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Endnotes

1. Clearly, innovative efforts may have many dimensions other than formal research activity such as shop-floor improvement forums, and work force initiatives. However these dimensions are difficult to capture in a systematic fashion. In this paper, such efforts are for the most part ignored and only studies focusing on formally reported R&D are included.
2. We thank one of the reviewers for pointing out this view to us.
3. However, more recently even neoclassical economists have significantly increased their study of cooperation between firms, more generally and specifically in connection with innovation, though again the focus has been more on what collaboration entails for the incentives to innovate (innovative effort) or what it implies for the distribution of downstream rents and welfare. Relatively little work has focused on the mechanisms by which collaboration may enhance innovation productivity or output. Link and Bauer (1989) use survey evidence to establish that participating in cooperative research ventures improves the rate of return to a firm's total R&D expenditure even though participation in cooperative research does not have any impact on the firm's total productivity growth. Hence, they provide indirect evidence of improved R&D efficiency through cooperation. They also provide descriptive evidence of the impact of cooperation on more direct measures of technological performance such as new patents, processes, and products. However, this component of their analysis establishes only that cooperative research results in new products and processes, but provides no basis for assessing whether cooperation increases or decreases the efficiency of the innovative process. This study, therefore, leaves the broader question of the impact of inter-firm collaboration on technical performance of firms unanswered.
4. Recent work on the theory of the firm indicates a similar trend even within the neoclassical paradigm with firms being recognized as offering different incentive structures and possessing different competencies (Holmstrom & Tirole, 1991; Milgrom & Roberts, 1988; Rotemberg & Saloner, 1993).
5. Cooperative arrangements may lead to more effective R&D because collaborators may have competence advantages in technologies and may therefore generate more knowledge/dollar of R&D. These advantages are analyzed later.
6. This result has antitrust implications in that firms combining similar knowledge are more likely to be competitors in the same product markets, than firms bringing together different skills. Such firms pose a greater collusive threat than firms who are likely to be operating in different product markets. Given that the benefits from collaboration between similar firms are lower, and the risks of anticompetitive action higher, there may be a valid case for distinguishing between collaborations involving firms in similar activities and linkages involving firms with dissimilar activities.
7. In fact, such linkages, where the partners bring in similar assets or competencies are often called "scale" linkages (Dussauge, Garrette, & Mitchell, 2000; Hennart, 1988). The above analysis shows that returns to scale are not a precondition for such linkages to provide benefits.

8. Leonard-Barton (1984) found that 84% of the technical talent of firms was reported to be found through network contacts rather than formal employment and job search procedures. Further, 42%, or half, of the network contacts were through indirect ties, or mutually known third parties, *vis-à-vis* an equal number, 42%, which emerged through current or past direct ties.
9. Scholars examining the role of top management teams have paid some attention to this construct (Hambrick et al, 1996; Bantel & Jackson, 1989); we shall discuss their work in greater detail in section 3.3.

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