# Chapter 6
# R&D Productivity and Firm Size in Semiconductors and Pharmaceuticals: Evidence from Citation Yields

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## ABSTRACT

*Using firm level panel data from the U.S., the authors explore the relationship between firm size and R&D productivity for two important and R&D-intensive industries: Semiconductors and Pharmaceuticals. They employ two measures of a firm's R&D performance: the number of citations received per patented innovation, and the number of citations received per dollar of R&D expenditures. The former is a measure of the average quality of a firm's patents, and the latter is a measure of total R&D output obtained per dollar of investments. The authors find that the average quality of patents (citations received per patent) falls with firm size in Pharmaceuticals, but there is no relationship between patent quality and firm size in Semiconductors. Citations received per R&D dollar decrease with size in both industries, which is due to the well-documented negative relationship between patents per R&D and firm size.*

## INTRODUCTION

The Schumpeterian hypothesis has been a source of much heated debate among economists. While some economists, starting with Schumpeter (1942), claimed that large enterprises are the primary engines of innovation and economic growth, others found evidence for both small-firm and large-firm advantages in innovation. The presence of large fixed costs in innovation (Galbraith, 1952), economies of scale and scope in R&D (Galbraith, 1952; Comanor, 1967), benefits of diversified product lines (Nelson, 1959), abil-

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ity to spread the risks (Nelson, 1959) and costs (Cohen & Klepper, 1996) of R&D projects, easier access to external financing (Galbraith, 1952; Rothwell, 1989), and possible advantages in the scientific labor market (Idson & Oi, 1999; Kim, Lee, & Marschke, 2009a) are commonly stated factors favoring large firm productivity. On the other hand, small firms may have advantages in performing R&D due to a (comparative) lack of bureaucracy (Scherer, 1980; Cooper, 1964; Blair, 1972), flexible decision making processes (Freeman & Soete, 1997; Rothwell, 1989) and a lack of the agency problems that may occur due to the incontractibility of the output of a single scientist in large firms (Lewis & Yao, 2001). Small firms are also argued to have better R&D performances since they tend to be more efficient receivers of spillovers (Acs, Audretsch, & Feldman, 1994; Audretsch & Vivarelli, 1994; Shimshoni, 1970). Since it is possible to state reasons for higher productivity in both small and large firms, the final verdict on the Schumpeterian hypothesis needs to come from empirical research (Scherer, 1980).

In this chapter, we perform an empirical test of the Schumpeterian hypothesis on two important R&D-intensive industries in the U.S: Pharmaceuticals and semiconductors. For this purpose, we use two different (but related) measures of a firm's R&D output: the number of citations received per patented innovation, and the number of citations received per dollar of R&D expenditures. The former is meant as a proxy for the average quality of firm's patents, while the latter is a proxy for total output achieved per dollar of R&D investments.

Focusing on individual industries has the advantage that economic units are technologically similar, thus citation counts belonging to different firms are comparable with one another. This, of course, comes at the cost of losing generality since we have to make inferences about relatively narrow industry classifications. An empirical analysis of larger magnitude that spans a large number of industry classifications needs to take additional caution to ensure that cross-industry differences in citation (and patenting) rates are not driving the main results. Such an effort is undertaken by Dindaroglu (2010), who addresses the same research question using a large panel of U.S. manufacturing firms, and discusses some of these issues in further detail.

## BACKGROUND

The relationship between firm size and R&D performance is among the most intensely debated questions in the economics of innovation. R&D performance is traditionally measured by patents (or patents per R&D dollar), or innovation counts. While there are conflicting results, the literature at large does not support the Schumpeterian hypothesis, and often finds evidence on the contrary. In an influential paper, Scherer (1965) studied the relationship between patenting and firm size for the 1955 cross section of the largest firms in U.S. He found that the number of patents increased less than proportionally with firm size for most of the sample, with the exception of a small number of very large firms. Bound et al. (1984) found that smaller firms obtained a larger number of patents per dollar of R&D expenditures in a 1976 cross section of U.S. manufacturing firms. Similar results have been found by Johannisson and Lindstrom (1971) in Swedish, and by Schwalbach and Zimmerman (1991) in German manufacturing. Therefore, such results are not confined to the U.S.

Some authors have utilized databases of significant innovations to study the relationship between firm size and innovation counts[1]. Pavitt, Robson, and Townsend (1987) used the database of significant innovations compiled by the Science Policy Research Unit (SPRU) of the University of Sussex to show that there is a U-shaped relationship between size and innovation intensity. Acs and Audretsch (1991a) concluded that the data supported the hypothesis of a negative