The Democratization of U.S. Research and Development after 1980

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Abstract

Using Compustat data, we document that prior to 1980, large R&D performing firms had higher R&D intensity (R&D/operating expenses) than small firms in the same industries. Over the course of the next two decades, in these same industries, small firms came to rival and even surpass large firms in terms of R&D intensity. During this period, corporate R&D intensity nearly doubled, and most of the aggregate increase is due to the substantial increase in R&D intensity among small firms. Little of the change in composition is explained by changes in the industrial distribution of R&D.

Why did small firms increase their R&D after 1980 and not before? We argue that, after 1980, small firms were able to compete on better terms in industries already dominated by large firms. We show that the patterns we observe in the data are consistent with a straightforward dynamic model of R&D with falling barriers to entry.

But what barriers fell? We argue that the shift in R&D intensity by small firms was largely due to the electronics revolution. Prior to the 1980s, a large corporate sales and clerical force was an essential factor for the rapid and widespread distribution of new products. This technology clearly favored large established firms. But the electronics revolution obviated the need for these factors, making entry easier.

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1. Introduction

Beginning around 1980, the personal computer made computation accessible to small firms, and firm investment in computers increased sharply. The change in scale made possible by the microprocessor, we shall argue, reduced barriers to entry and enabled small firms to become more important contributors to U.S. research and development (R&D).

Until 1980, large economic actors – the federal government and large firms – dominated research and development in the United States. Figure 1, which shows spending on research and development by source relative to gross domestic product, illustrates that most of U.S. R&D was being funded by the federal government before the 1980s. The share of corporate-funded R&D rose from the mid-1960s, but that was primarily because federal R&D was falling. Indeed, between 1969-79, corporate R&D barely kept pace with GDP; since then it has grown considerably more rapidly.

Why did this acceleration occur? The answer is the growth in R&D conducted by smaller firms. In 1980, firms with 5,000 or fewer employees accounted for only 15 percent of U.S. corporate R&D. This share has grown over time. Over the course of the next two decades the ratio of U.S. corporate R&D to GDP nearly doubled, but almost all of the increase was accounted for by smaller firms (Figure 2). Why did small firms increase their R&D after 1980? We argue that, to a substantial extent, it was because small firms were better able to compete in new product markets.

Using Compustat data, we document that prior to 1980, large R&D performing firms (measured in employees and in revenues) had higher R&D intensity (as measured by R&D divided by operating expenses) than small firms in the same industries. Over the course of the next two decades, in these same industries, small firms came to rival and even surpass large firms in terms of R&D intensity.

We point out that in the Compustat data, R&D remained highly concentrated in 49 (three-digit SIC) industries.[1] Indeed, the concentration increased rather than dispersed, despite the fact that the proportion of all firms conducting R&D has risen. In 1974, 83 percent of R&D was performed in these industries; in 1999 they accounted for 92 percent of R&D.

Indeed, most of the R&D in these industries was performed by very large firms—firms with 25 thousand or more employees. These long-term incumbent firms were protected by barriers to entry into product markets according to Chandler (1994). These barriers were the result of large-scale investments in a corporate structure whose core purpose was information processing: the sales and administrative staff. This staff in turn enabled the long-term incumbent to sell new products in sufficient volume to justify large investments in new product development. Stein (1997) models this type of investment in a

[1] Our analysis (below) relies on even finer industry definitions, but the conclusion is the same.

customer base, which we call marketing capital.

The microprocessor revolution of the late 1970s and early 1980s created a general purpose technology. One effect was that, as economies of scale of information processing fell, relatively small firms could quickly transact large volumes of new products since, for the first time, they were able to automate business information processing.[2] Its empirical counterpart was an increase in the economic resources devoted to investments in computers and peripheral equipment, as measured by its ratio to GDP in nominal terms. (It is hard to discern the sharp break in the general usefulness of computers from the price index for computers and peripheral equipment, which fell roughly at the same rate from 1960 to 1975, -21 percent annually, as it did from 1975 to 1985, -19 percent annually).

The microprocessor revolution also reduced the cost of performing R&D. We use a simple model, adapted from Stein, to differentiate the effects of different types of reductions in the cost of innovation. Our empirical work then examines the effect of computerization on the responsiveness of own R&D to the R&D of rivals, and on the market value of R&D. We also differentiate across industries and firms by separating out long-term incumbent firms by size: we examine firms that had more than 25 thousand employees in 1965 and their industries to analyze how the presence of these firms influenced the nature of competition.

Our theory suggests that falling barriers to entry should increase the overall R&D intensity of firms and this results from an outward shift in the R&D reaction function of smaller, younger firms. All else equal, the market value of entrant firms should rise, while the value of incumbent firms should fall. In our regressions,we find that computerization increased the R&D interaction between firms, so that firms did more R&D in the year following increases in their rivals' R&D. We also find that computerization tended to reduce the market value of assets among incumbent firms while increasing the value of non-incumbent firms. Computerization increased the market value of ongoing R&D investments among all firms, but particularly among incumbent firms. This is consistent with the model, which suggests that as the cost of marketing capital declines, incumbents worry less about replacing their existing profits and compete more aggressively in R&D in order to deter entry.

1.1. Related Literature

The literature that relates rivals' R&D to own firm R&D and to various measures of output (such as market value) dates back to the 1970s and includes, for example, Grabowski and Baxter (1973), Bernstein and Nadiri (1989), and Cockburn and Henderson (1994).

[2] Prior to this time, a power law – dubbed Grosch's law – held in computerization, which was that system power increased with the square of system cost (Mendelson 1987). Hence the most efficient systems required sufficient scale to amortize the required investment. Mendelson documents that these economies of scale disappeared in the 1980s.

The empirical paper most closely related to our work is Bloom et al. (2005). They explain movements in firm R&D and market value with regressors constructed by aggregating rivals' R&D two ways: using weights of technological-relatedness of the firms (measured by the technology classes of firm patents) and weights of market-relatedness (measured by the SIC codes of product market segments) to identify technology spillovers and product market rivalry. Their striking result is that technologically related rivals' R&D increases market value, while market-related rivals' R&D reduces market value. They also find that both types of rivals' R&D increases own R&D. Our interest is in how R&D spillovers and outcomes change as a consequence of computerization. We interact computerization over time with rivals' R&D to study increases in spillovers as entry barriers fall.

Another long and active strand of research has related industry structures to research and development. Recently this work has looked to competitive policy reforms to identify exogenous changes in product market competition; the paper by Aghion et al. (2002) is a good example. They find that there is an inverted U-shaped relationship between product market competition, as measured by price-cost margins, and innovation, as measured by patenting activities.

The third literature to which our paper relates discusses how the economy has changed since the late 1970s. In general, these papers suggest that the number of new products increased, entry occurred, and volatility and risk experienced by firms rose. Bils and Klenow (2001) argue that product variety accelerated after 1980. The value of R&D fell in the late 1980s (Hall, 1993). The stock market value of an older generation of firms fell (Greenwood and Jovanovic, 1999) and a new generation of firms arose (Jovanovic and Rousseau, 2001). Idiosyncratic firm risk rose beginning in 1980 as measured by stock market valuations (Campbell et al., 2001, and Comin and Philippon, 2005), while corporate CEOs' tenure became shakier (Huson, et al., 2001.) All these papers are consistent with the notion that R&D competition intensified, which is what we explore.

1.2. Marketing Capital as a Barrier to Entry

In this paper we set forth a model in which established firms initially have an advantage in investing in new product development because of its past investment in marketing capital. This model is a simplification of Stein (1997). Our model varies from Stein in that we focus on the impact of a decline in the cost of this investment; the personal computer revolution in the late 1970s is modeled as a decrease in the price of marketing capital

There are two firms, an incumbent that currently monopolizes the market and a potential entrant. Either or both may choose to engage in risky R&D. Successful innovations are drastic; that is, they entirely displace the existing product in the market. If the incumbent successfully innovates, it implements the superior technology and earns additional profits. If the entrant successfully innovates, before it can enter the market, it must first invest a lump-sum in order to establish its own customer base. If both firms successfully innovate, and the entrant sinks its investment in marketing capital, the two firms will compete in prices. In equilibrium, the entrant would never choose to do so, as it could not amortize the cost of its marketing capital. Entry, then, is observed only where the entrant is the only successful innovator, and the associated rents are sufficiently large.

The likelihood of success for the entrant depends on the research intensity of the incumbent, which reduces the probability of successful entry. Conversely, the research intensity of the entrant influences how much weight the incumbent places on its current profit stream when determining how much it should invest in an innovation that will displace what it already has. We examine the behavior of the incumbent and potential entrant as we vary the magnitude of the cost of marketing capital. We show that the entrant is more likely to invest in R&D and enter the market, as the cost of marketing capital falls relative to the profits currently earned by the incumbent. Thus the model suggests an unambiguous hypothesis about the behavior of new firms as the cost of deploying complementary assets falls.

The effect of such changes on the behavior of incumbents is more complicated. We show that the incumbent will invest either more or less in R&D than the entrant. When the cost of new marketing capital exceeds the current rents enjoyed by the incumbent, the entrant does not engage in R&D. There is no interaction, and the model is the standard monopoly problem.

As the cost of marketing capital is reduced, the entrant will eventually find it worthwhile to engage in R&D. This has the effect of increasing the incumbent's incentive to engage in R&D as the replacement motive is diminished and greater incumbent R&D reduces the entry incentive. Still, as the cost of marketing capital continues to fall, the entrant will perform more and more R&D, eventually doing more R&D than the incumbent if current profits are sufficiently high.

We argue that the predictions of the model are observed in the data. After 1980, smaller and newer firms became more research intensive in both absolute terms and relative to larger or older firms. Incumbents also raised their research intensity. A variety of other factors might also explain the changing patterns in R&D investments. For example, computerization or globalization might increase the productivity of R&D in the sense of genearting more profit per dollar of R&D invested. We use other implications from model, in particular for the market value of firms, to rule out this explanation.

2. A Simple Model of R&D with Marketing Capital

There are two firms: an incumbent (i) and a potential entrant (e).[3] At the beginning of the game, the incumbent is the only active producer and

[3] In the appendix, we generalize the model to allow for more than one entrant.

earns a monopoly profit $\pi > 0$. Both firms have access to a common stochastic R&D technology. Firm j chooses a probability of success θ^j, which costs $-rLn(1-\theta^j)$, where r is the price of R&D relative to final output. Firms chose their R&D simultaneously, taking their rival's strategy as given. Nature then determines the success or failure of the firms' R&D programs (we assume these draws are independent). A successful innovation results in a new level of profits $\tilde{\pi} > \pi$, gross of R&D costs. This innovation is drastic; i.e., the new product drives the old one completely out of the market. In order to produce, a successfully innovating entrant must then sink $b > 0$ to establish its distribution network. If both firms successfully invent, and the entrant sinks b, they compete in prices, resulting in zero gross profits.

2.1. Equilibrium Outcomes

The objective functions of the entrant and incumbent, respectively, are simply

$$\underset{\theta^e\in[0,1]}{Max}\left\{V^e = \theta^e(1-\theta^i)[\tilde{\pi} - b] + rLn(1-\theta^e), 0\right\} \text{ and}$$

$$\underset{\theta^i\in[0,1]}{Max}\left\{V^i = \theta^i\tilde{\pi} + (1-\theta^i)(1-\theta^e)\pi + rLn(1-\theta^i), (1-\theta^e)\pi\right\}.$$

Assuming an interior equilibrium, the first order conditions imply the following R&D reaction functions for these firms:

$$\hat{\theta}^e = 1 - \frac{r}{(1-\theta^i_e)[\tilde{\pi} - b]} \qquad \text{and} \qquad \hat{\theta}^i = 1 - \frac{r}{\tilde{\pi} - (1-\theta^e)\pi}. \tag{1}$$

It is readily apparent that the reaction function for the entrant is downward sloping, while it is upward sloping for the incumbent. This makes it possible for an incumbent to discourage entry, as long as it has sufficient incentive to do R&D (see below).[4] In our empirical estimation, we expect the slope of the entrant's reaction function to be smaller, at least initially, than the one for the incumbent.

Closed form solutions for the equilibrium R&D intensities take the form:

$$\tilde{\theta}^e = \frac{\pi - b}{\tilde{\pi} + \pi - b} \qquad \text{and} \qquad \tilde{\theta}^i = 1 - \frac{r}{\tilde{\pi} - b}\left(1 + \frac{\pi - b}{\tilde{\pi}}\right) \tag{2}$$

An *interior* equilibrium does not exist for all possible combinations of the exogenous parameters $(\pi, \tilde{\pi}, r, b)$. The various possibilities are depicted in Figure 3, which collapses the parameter space into two dimensions (π, b) relative to $\tilde{\pi}$.

In general, the most R&D is observed for small values of π and b (the lower left portion of the parameter space). The least amount of R&D is observed

[4]It is easy to verify that in markets characterized by two symmetric incumbents (or entrants) the reaction functions of both firms are downward sloping.

for higher values of π and b (the upper right portion of the parameter space). For example, the entrant will never do R&D if there are insufficient profits to amortize both R&D and the cost of marketing capital, i.e., where $\tilde{\pi} - b - r \leq 0$ (region I and the upper portion of region II). Similarly, the incumbent will not do any R&D if it costs more than the incremental gain in profits if successful, i.e. where $\tilde{\pi} - \pi - r \leq 0$ (also region I). In addition, whenever the incumbent's existing rents are less than the cost of marketing capital for the entrant, the incumbent will always do enough R&D to deter entry (the lower portion of region II). Region IV characterizes the opposite possibility: where b is sufficiently small, and π is sufficiently large, entry is assured and the incumbent chooses not to engage in R&D. This occurs where $r\pi \geq (\tilde{\pi} - b)(\tilde{\pi} - r)$.[5] In region III, both the incumbent and entrant engage in R&D. This region can be divided into subregions of the parameter space where the incumbent does more R&D than the entrant and where the opposite is true.[6]

In region III of the parameter space, the equilibrium expected value of rents earned by the incumbent and the entrant, respectively, are

$$\begin{aligned} V^i &= \tilde{\pi} - r + rLn\left(\frac{r}{\tilde{\pi}}\left(\frac{\tilde{\pi} + \pi - b}{\tilde{\pi} - b}\right)\right) \text{ and} \\ V^e &= r\left(\frac{\pi - b}{r}\right) + rLn\left(\frac{\tilde{\pi}}{\tilde{\pi} + \pi - b}\right). \end{aligned}$$

The model is as simple as can be and yet yields a rich set of comparative static results in terms of the R&D expenditures and ex ante market values of the incumbent and a prospective entrant. For our purposes, the question is how the behavior of incumbent and entrant firms changes as we reduce the cost of marketing capital (in our figure, fix $\tilde{\pi}, \pi$, and r and then observe the change in regions as we reduce b). We might start with an R&D intensive industry dominated by an incumbent and eventually observe entry, initially by firms that are not as R&D intensive as the incumbent (a movement from region II to III). Alternatively, we might begin with an industry that is not R&D intensive and eventually observe entry by R&D intensive firms, and if b falls enough, the incumbent might also start doing R&D (a movement from region I to IV and finally into III). In the latter case, we might observe equilibria where either the incumbent or the entrant does more R&D than its rival.

2.2. *Identifying the Effects of Changes in Marketing Capital*

In our empirical analysis of actual firm behavior, we examine the effects of changes in various parameters on the R&D intensity and the market value

[5] Note that in Figure 1, the boundary of this region is drawn assuming that $2r < \tilde{\pi}$. If $2r > \tilde{\pi}$,this point would lie on the x axis between $\tilde{\pi} - r$ and $\tilde{\pi}$.

[6] In Figure 3, the boundary dividing these two subregions is illustrative. The actual boundary is defined by the equality $\tilde{\pi}^2(\tilde{\pi} - b) - r(\tilde{\pi} + \pi - r)^2 = 0$, which is derived from the difference between the two expressions in (2).

of incumbent and non-incumbent firms. We also estimate R&D reaction functions of these firms and examine the change in their slopes and intercepts over time. We argue this is sufficient to identify the predominant effect of changes in barriers to entry on firm behavior. This identification strategy follows from the comparative static results of the model, which are described in Table 1.[7] Notice, for example, that declines in the cost of marketing capital and the relative price of R&D are associated with similar (but not identical) changes in the R&D and reaction functions of incumbent and entrant firms, but very different implications in terms of changes in firm value.

Another factor during this time period was globalization, which increased the size of the market. This would tend to raise invention size, rents, and the cost of marketing capital together, while leaving R&D costs unaffected. Thus globalization can be modeled as a fall in the relative cost of R&D. The globalization that occurred under the gold standard required large firms – that was the period in which Chandler's great industrial firms established their hegemony.

2.2.1. Accounting for entry by more than one firm

A pure duopoly model may not be sufficient to characterize all the effects of falling barriers to entry over time. In the appendix, we present results of the model generalized to allow for the possibility of entry by more than one firm. We do this by adding a second fixed cost (c) that entrants must sink prior to engaging in R&D. For an appropriately chosen value of c, there exists a non-empty region of the parameter space where two firms will enter. This region is defined by a participation constraint whose boundary lies everywhere below the upper boundary of Region III in Figure 1. Thus in the richer model, the incumbent encounters a competitive fringe.

Consider two economies that differ only in the magnitude of the fixed cost of R&D. In the second economy, c is such that two firms are just indifferent about entering. In the first economy the fixed cost of R&D is $c + \varepsilon$. In the appendix, we show that all firms do less R&D in the second economy than in the first, and yet the probability of at least one successful innovation is higher in the second. And while the two entrants each do less R&D than the single entrant in the first economy, the sum of their R&D is higher. The ex ante value of the incumbent is higher in the second economy. The ex ante value of the entrant in the first economy is larger than in the second, where it is zero.

For changes in the exogenous parameters that do not induce additional entry, the results reported in Table 1 remain valid for the case of two active entrants. For example, as b falls, all firms will do more R&D, the value of the incumbent falls and the value of entrant(s) rises. If instead we consider reductions in c, the value of entrant firms rises, but there is no effect on the value of the incumbent unless an additional firm enters. In that case, the value

[7] We omit the derivation of these results as they follow directly from the closed forms in Figure 1, and the reaction functions (above).

of the entrants again falls to zero. And unless additional entry occurs, there is no change in the R&D performed by any firm. Thus we can use changes in R&D to distinguish between declines in the cost of marketing capital and declines in the fixed cost of R&D.

3. Data

We test our theory by using annual Compustat data from 1950 to 1999. Compustat compiles its data primarily from corporate annual reports and SEC filings. The data differ from NSF data along two dimensions. One is the nature of the universe: the NSF and Compustat may observe the same R&D at a different ownership level; typically, we believe that the NSF may be obtaining information from a subsidiary company whereas Compustat records data from a parent. The other is completeness – Compustat is a data set of security-issuing firms, while the NSF aims at measuring the R&D universe through a suitable random sampling frame. These data explicitly exclude federally funded R&D; they generally represent R&D expensed out of private corporate resources.

We define R&D as reported R&D expense, Compustat no. 46. We identify firm size by numbers of employees, Compustat no. 29. To measure R&D intensity we use data on operating expense, which we define as cost of goods sold (Compustat no. 41) plus selling, general, and administrative expenses (Compustat no. 189). Operating expense is a better measure of nominal firm scale than sales for those new firms that do not have substantial sales; this is important for small research-intensive firms. Typically R&D is expensed rather than capitalized and is thus included in operating expense, in which case the ratio of R&D to operating expense will be less than or equal to one, reducing the need to censor observations.

Because we wish to focus on strategic interactions between firms (see below), we define industries narrowly. We count four-digit SIC codes as separate industries whenever there are at least five firms with 30 or more years of financial data over the years 1950-99. For industries that do not meet this criterion, we aggregate to the three-digit SIC level, excluding those firms in the four-digit industries that meet our criterion. This results in 196 separate industries. We calculated an overall R&D intensity for these industries, dividing the sum of R&D expenditures by the sum of sales and identify 69 with a ratio of R&D to sales of 1 percent or higher in 1973. We call these R&D industries; they form our study subject.[8]

We want to identify long-lived, large industrial corporations as our incumbent firms. We choose firms with more than 25 thousand employees in 1965 that are in R&D intensive industries (defined above).[9] We identify 65 of these

[8]Details of our data set construction are found in a separate appendix available from the authors.

[9]We have omitted GTE, a telephone company operator that had a subsidiary with R&D,

firms spread across 28 R&D industries (Table 2).[10] Together, these firms in 1974 accounted for 55 percent of the R&D performed by all private corporations reported in Compustat and for 77 percent of the R&D in their industries in that year (Table 3). Within their industries, these firms represented just 5 percent of all firms, but 73 percent of the operating expenditures.

We call these firms incumbents, because not only are they large firms but most of them had been large for an extended period of time. 44 of the 65 are listed in Chandler's list of the 200 largest U.S. industrial firms for the year 1948; and 34 were on Chandler's top 200 list for 1930. Moreover, as late as 1983, 58 of the 65 still had at least 25 thousand employees. Thus the majority of these firms were among the top industrial firms in the U.S. for half a century, and nearly all were very large for two decades or more. These large industrial firms are primarily makers of durable goods such as transportation equipment (including aerospace, cars, and tires), business equipment (computers, electrical, construction, farm, and office), and glass. The list also includes chemical producers, including pharmaceuticals, and a few producers of consumer goods.

One concern in this analysis is that the rise in computer share necessarily has a more complex interpretation for the computer industries, which we define as including electronic computers (SIC 357), electronic components (SIC 367) and computer software (SIC 737). For these industries, the rise of the microprocessor has complex effects on demand, supply, market value, and R&D. We therefore separate these industries from the non-computer industries. It is worth considering that the dominant firm in these industries was IBM, which initially was the main developer and beneficiary of the personal computer, and at the same time dominated mainframes, produced its own-non PC electronic components, and was the largest software producer. The computer industries include 5 long-term incumbents; while there are 60 in the non-computer R&D industries.

For the non-computer industries, we divide the total into two types: the industries that include long-term incumbents, which we call incumbent industries, and industries without incumbent firms. Our empirical strategy will be to focus mostly on the strategic interaction between incumbents and non-incumbents in noncomputer incumbent industries, as it is there that we expect to see the cleanest test of our hypothesis about marketing capital.

Table 3 shows two basic trends. First, the R&D-intensive industries increased their share of R&D, as measured in Compustat; non-R&D-intensive firms' share of R&D fell from 16.8 percent of U.S. industrial R&D to 7.6 percent. This justifies our focus on R&D-intensive industries: the others are largely irrelevant to the rise of business R&D expenditures. Second, the share of incumbent firms in R&D falls both in computer and noncomputer indus-

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Sylvania; telephone companies were heavily regulated throughout most of this period, with most of the R&D performed by the jointly held Bell Labs.

We also have omitted Clevite Corporation, Douglas Aircraft, and R R Realizations, which disappeared in the merger wave of the 1960s, before our regression analysis.

[10] There are an additional 73 incumbents in non-R&D-intensive industries.

tries. The share of all private R&D accounted for by incumbent firms in R&D industries has fallen over time, from 55 percent in 1974 to about 35 percent in 1999, with most of this decline occurring during the 1990s. In 1974, the share of R&D spent in these industries attributable to non-incumbent firms was only 23 percent; in 1999 they accounted for 45 percent. Thus while R&D remains concentrated within a narrow set of industries, a rising share of this R&D is being performed by younger, smaller firms. And, as Figure 2 shows, this is not simply an artifact of the loss of incumbents over time; rather it is the increasing economic importance of R&D among smaller firms. It is this central fact which we seek to explore.

4. Empirical Results

We turn first to the patterns in R&D intensity among the various categories of firms defined in the previous section. According to our model, as the cost of marketing capital falls, entrants should perceive the incumbent's markets as more vulnerable and this should increase competition in R&D. We expect all firms, and particularly our long-term incumbents, to increase their R&D in response to R&D by their rivals.

Table 4 documents the distinct rise in R&D intensity of U.S. non-incumbent firms over time. It was significantly higher in 1999 than in 1974 for non-incumbent firms whether in computer industries, incumbent industries, or non-incumbent industries (the p values for the F statistics are all less than 0.01). In the noncomputer industries, incumbent firms also increase their R&D (again the p value is less than 0.01). In contrast, in the computer industries, the five incumbents begin with the highest R&D intensity, but actually have a lower R&D intensity by 1999.

In 1974, incumbent firms had an R&D intensity higher than the the R&D intensity of non-incumbent firms. This was true for incumbents in both the computer and non-computer sectors (p values for the 1-sided test of 0.006 and 0.042, respectively). By 1999, however, the incumbent firms have lower R&D intensities than non-incumbents in the same industries, but the difference between them is at best marginally significant – at the one-sided 10 percent level for the computer industries, and not significantly different for the other industries. Thus we have clear evidence that non-incumbent firms switched from lower R&D intensities to at least equal R&D intensities over this period.

Next, we analyze how research and development expenditures and firm market value were affected by changes in the cost of marketing capital. We proxy this cost by its dual, the rate of investment in computer hardware, using the nominal business fixed investment in computers and peripheral equipment as a share of nominal gross domestic product, which we call $Comp_t$. This ratio has risen over time (Figure 4). We restrict our regressions to the period from 1973 to 1997; the earlier date is the date from which we have reasonably complete data on R&D, and the latter date is chosen to exclude the worst effects of the Internet bubble in 1998 and after.

4.1. R&D Regressions

First, we examine the reaction of firms' research and development to the lag of rivals' R&D. All our regression data are scaled by operating expense, defined above. The lag of rivals' R&D is simply

$$(R\&D/OpExp)_{jt-1}^{\tilde{}i} \equiv \frac{\sum\limits_{k \neq i} R\&D_{kjt-1}}{\sum\limits_{k \neq i} OpExp_{kjt-1}}$$

where i and k are firm subscripts, j is a three-or four-digit industry group, and t is time. We begin by estimating a simple reaction function regression where the left-hand side is own R&D expenditures (scaled by own operating expenditures) and, on the right-hand side, a one-year lag[11] of the comparable R&D intensity of the firm's rivals, i.e., that of the other firms in the same industry (defined above):

$$\frac{R\&D_{it}}{OpExp_{it}} = \alpha_0 + \alpha_1 * \left(\frac{R\&D}{OpExp}\right)_{t-1}^{\tilde{}i} + \alpha_2 * Comp_{t-1} * \left(\frac{R\&D}{OpExp}\right)_{t-1}^{\tilde{}i} + u_i + v_t + \epsilon_{it}$$

where u_i are firm-specific effects and v_t are year effects. We have 4,029 firms in all, averaging just over eight annual observations per firm (descriptive statistics are found in Table 5a). We also include an interaction of rivals' R&D intensity with computer share, measured in percentage points of GDP. What we expect to see is that as computerization rises, firms compete in R&D markets more aggressively, by increasing their R&D in response to others in the same industry increasing their R&D.

In our regressions, we separate computer industries from the non-computer industries. As we have pointed out, the interpretation of the behavior of computer industries during this period is necessarily ambiguous. For the non-computer industries, we separate incumbent industries from non-incumbent industries. Within the incumbent industries, we allow different responses between the long-term incumbents themselves and the other firms in the industries.

The results for the simple specification are reported in Table 6. The coefficient on the term $Comp_{t-1} * (R\&D/OpExp)_{t-1}^{\tilde{}i}$ for incumbent industries is positive as we expect. We can compute the overall impact of a change in rivals' R&D on own R&D as the sum of the coefficient on rivals R&D and the coefficent on the interacted term times $Comp_{t-1}$. The $Comp_{t-1}$ variable rises from 0.28 to 0.93 over the period 1973 to 1997, so the net effect of rivals' R&D goes from 0.22 to 0.59. Over time, the reaction of firms' R&D expenditures to that of their rivals triples in intensity. Since rivals' R&D has nearly half the variation of own R&D, the net effect of 0.59 suggests that more than one-quarter of "within" movements in R&D can be accounted for by this reaction by the end of the period.

[11] Similar results are obtained using contemporaneous values

We expect to find a somewhat different interaction between the long-term incumbents and their rivals than in the industries without incumbent firms. What we find is that there is a higher degree of strategic interaction in the industries with incumbent firms, and this strategic interaction rose as computerization increased. For long-term incumbents, the coefficient on rivals' R&D is 0.83, a stronger reaction than for non-incumbents in the same industries. Since rivals' R&D has a "within" standard deviation that is two-thirds the size of that for own R&D, the impact of rivals' R&D accounts for more than 60 percent of own R&D by the end of the period. This substantial economic impact is reflected in the large proportion of R&D accounted for by the regression (the "within" R^2 is 0.39). While firms other than the long-term incumbents have a smaller coefficient on the interaction of computer share and rivals' R&D (lagged), it is still larger than for firms in other industries.

In non-computer, non-incumbent industries, research and development expenditures are overall negatively related to rivals' R&D lagged, as implied by the model. As computerization increases, the relationship remains negative but is attenuated over time. For computer industries, an insignificantly negative interaction becomes a signficantly positive interaction.

4.1.1. Adding patents to the R&D regressions

The temporal relationships that define the basic reaction function regressions do not include any variables that might capture variations in technological opportunities across industries and time. A logical measure to consider is the number of patents obtained by firms, a noisy indicator of success in the R&D process (Griliches 1990).[12] We therefore add the lag of the number of patents received by the firm, and its rivals, again normalized by operating expenses, to our regression. This is an empirical analogue for r, the relative cost of R&D (the inverse of the productivity of R&D) in our model. We also include an interaction of these patent variables with our measure of computerization to examine the simultaneous effects of declining barriers to entry and increases in technological opportunity. Our specification is then

$$\begin{aligned}\frac{R\&D_{it}}{OpExp_{it}} = {} & \alpha_0 + \alpha_1 * \left(\frac{R\&D}{OpExp}\right)^{\tilde{}i}_{t-1} + \alpha_2 * Comp_{t-1} * \left(\frac{R\&D}{OpExp}\right)^{\tilde{}i}_{t-1} \\ & + \alpha_3 * \left(\frac{Patents}{OpExp}\right)^{i}_{t-1} + \alpha_4 * Comp_{t-1} * \left(\frac{Patents}{OpExp}\right)^{i}_{t-1} \\ & + \alpha_5 * \left(\frac{Patents}{OpExp}\right)^{\tilde{}i}_{t-1} + \alpha_6 * Comp_{t-1} * \left(\frac{Patents}{OpExp}\right)^{\tilde{}i}_{t-1} \\ & + u_i + v_t + \epsilon_{it}\end{aligned}$$

Our patent data are derived from the NBER Patent Citations Data File (Hall, Jaffee, and Trajtenberg 2001). But not all publicly traded firms are

[12] We are not concerned about the noise typically associated with this measure (e.g., variations in patent propensity) as it is likely absorbed in the firm and time effects.

matched to their patents and so our sample size shrinks (descriptive statistics for the observations included in this regresssion are found in Table 5b). There is also a concern about selection–the firms successfully matched to their patents in the NBER data set may somehow be different from those that are not.[13]

The results are reported in Table 7. The coefficients on the interaction of computer share and rivals' lagged R&D intensity are generally unchanged, even slightly increasing, and the differences in these coefficients across the different categories of firms remain marked. In all cases, the coefficients remain statistically significant.

As expected, increases in own lagged patents, when interacted with computer share, is positively related to R&D (with the exception of non-incumbent industries). The coefficients are statistically and economically significant. In the non-incumbent indusries, R&D intensity falls in response to increases in their rivals' patenting, but this is offset over time as computerization increases. The opposite occurs for incumbent firms, whose R&D is higher when their competitors tend to patent more. This effect, however, is reversed as computerization increases.

Overall, we have found strong evidence that the fall in the cost of marketing, as proxied by computerization, sharply increased strategic interaction in R&D-intensive industries.

4.2. Market Value Regressions

According to our basic model, the increased competitiveness of R&D markets should lower the market value of R&D performing incumbents but raise the market value of R&D performing entrants. However, the latter result may not hold when more than one firm is able to enter. In that case, there are discontinuities in the effects of changes in marketing capital on the value of firms and these discontinuities are larger for the entrants. Moreover, once firms successfully enter, they become incumbents (albeit perhaps in small markets). And because there is more competition, the market value they gain from R&D is likely to be lower than before marketing capital fell in price.

In our empirical specification market value (MV) is equal to the shares outstanding (adjusted for stock splits) at the end of the year, times end-of-year price. We estimate the contribution to firm market value from its tangible capital and its ongoing intangible investments (e.g., R&D). For tangible capital, we use the book value (BV) of the firm's assets (including net financial assets). Book values are, like our market values, end-of-the-year values. We also include a one year lag of the patents obtained by the firm's rivals. Again, these variables are normalized by operating expenses. We include in the regression a time trend, our measure of computerization and its interaction with the other variables. We estimate the model on demeaned variables, allowing for an implicit fixed effect and a correction for selection (descriptive statistics

[13] To explore this possibility, we estimated a Heckman selection model on demeaned data (not shown) and obtained results qualitatively similar to those reported here.

for the observations in this regression are found in Table 8).[14] The specification is then

$$\begin{aligned} \frac{MV_{it}}{OpExp_{it}} &= \beta_0 + \beta_1 * t + \beta_3 * Comp_t \\ &+ \beta_4 * \frac{BV_{it}}{OpExp_{it}} + \beta_5 * Comp_t * \frac{BV_{it}}{OpExp_{it}} \\ &+ \beta_6 * \left(\frac{R\&D}{OpExp}\right)_t^i + \beta_7 * comp_{t-1} * \left(\frac{R\&D}{OpExp}\right)_t^i \\ &+ \beta_8 * \left(\frac{Patents}{OpExp}\right)_{t-1}^{\tilde{i}} + u_i + \epsilon_{it} \end{aligned}$$

Results are reported in Table 9. First note that the coefficient on book value in all cases is significantly greater than unity. One interpretation of this coefficient is that it is a measure of marginal q, reflecting the rise in market value with additional tangible investments. This interpretation suggests market power and, in turn, may reflect the success of R&D, which itself confers market power.

Next, as computerization increases, the market value of incumbent firms falls (negative coefficients on $Comp_t$ and its interaction with tangible assets). Thus, the decline in the cost of marketing capital reduces the value of the long-term incumbents. In addition, the coefficients on book value, which are generally greater than one and suggestive of market power, tend to be reduced as the cost of marketing falls. This accords with our notion that the falling cost of marketing capital tends to reduce market power. This is notably true for incumbents; the net coefficient on book value is reduced to close to one by computerization.

Now consider the row of coefficients for R&D expenditures. For all industries, taken as a whole, we get the results we expect. Initially, own R&D expenditures are valued at a high multiple, close to 3. Over time, as the cost of marketing capital falls, R&D falls in value. This may reflect the crash in value of research and development documented by Hall (1993b).[15] On the other hand, the details for our industry groups are different. The R&D coefficient is significant only in the computer industry. Over time, as the cost of marketing capital falls, R&D falls in value in the computer industry but rises among firms outside computers. These gains are concentrated in the incumbent industries outside computers, and especially among the incumbent firms. For many incumbents, it appears their R&D remained a source of monopoly

[14] The selection equation fits a probit model of the probability that a firm's rivals are matched to their patents using firm size (deflated assets) and year dummies as explanatory variables.

[15] Hall and Kim (2000) report some evidence of a modest recovery in the market value of R&D among U.S. firms in the 1990s.

profits, despite increased entry, and that their R&D efforts were often successful. This pattern is consistent with the model – incumbents become less concerned about replacing existing profits and more concerned about deterring entry through a more aggressive R&D strategy, which can preserve what rents are left to them. Thus the crash in the value of R&D expenditures does not appear to have happened to long-term incumbents, at least taken as a group. Rather, the decline in stock market value of incumbents appears to be reflected in a decline in the value of their other complementary assets.

Finally, the coefficient on the rival patent variable, our measure of techonological opportunity (the inverse of r in the model), is positive for incumbent firms and negative for all other firms outside the computer industries (these coefficients are all statistically significant). This too is consistent with the model – when R&D is more productive, incumbents are more aggressive in their R&D, which reduces the prospects for successful entry.

5. Conclusion

We have hypothesized that the rise of computerization made market entry into R&D-intensive industries easier. We argue that computerization reduced the cost of marketing capital. Under our model, computerization should increase R&D activity by both entrant and incumbent and should lower the market value of R&D by incumbents. The evidence we have presented shows clearly that as computerization increased R&D by all firms increased.

Overall, as computerization increased, the market value of firms fell, but this appears to have been primarily due to R&D by rivals, rather than a direct decline in the value of R&D. And surprisingly, the large long-term incumbents – while they had to respond vigorously to R&D by rivals – were able to retain a large part of their market value, unlike smaller incumbents.

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Appendix: Allowing for Additional Entry

For brevity, we examine here only the cases where 0, 1, or 2 firms decide to enter. We modify the objective functions in the text to include a fixed cost (c) that entrants must sink if they are to engage in R&D. The number of firms entering into the R&D stage is then determined by a zero profit condition.

Allowing for multiple entry introduces a complication: Under Bertrand competition, when more than one entrant successfully innovates and the incumbent does not, there is no pure strategy equilibrium. Instead, we examine an equilibrium where entrants use mixed strategies in their decision to sink b. In the symmetric case, the probability of sinking b, denoted α, is determined by the expression $\alpha(1-\alpha)\left[\tilde{\pi}-b\right]-\alpha^2 b=0$,which implies that $\alpha=(\tilde{\pi}-b)/b$.

The resulting firm value functions are then

$$V_2^j = \theta_2^j(1-\theta_2^k)(1-\theta_2^i)[\tilde{\pi} \ - b] + rLn(1-\theta_2^j) - c$$

$$V_2^i = \theta_2^i\tilde{\pi} + (1-\theta_2^i)\left\{(1-\theta_2^j)(1-\theta_2^k) + \theta_2^j\theta_2^k(1-\alpha)^2\right\}\pi + rLn(1-\theta_2^i)$$

where j and k denote the entrant firms and we use a subscript to distinguish this problem from the case with a single entrant.

The first order conditions when the entrants choose symmetric R&D intensities are

$$\frac{\partial V_2^e}{\partial \theta_2^e} = 0 \Longrightarrow (1-\theta_2^e)^2(1-\theta_2^i)\left[\tilde{\pi}-b\right] = r, \tag{3}$$

$$\frac{\partial V_2^i}{\partial \theta_2^i} = 0 \Longrightarrow (1-\theta_2^i)\left\{\tilde{\pi} - \pi\left[(1-\theta_2^e)^2 + (\theta_2^e(1-\alpha))^2\right]\right\} = r\ . \tag{4}$$

The corresponding reaction functions are then

$$\widehat{\theta}_2^e = 1 - \sqrt{\frac{r}{(1-\theta_2^i)\left[\tilde{\pi}-b\right]}}, \tag{5}$$

$$\widehat{\theta}_2^i = 1 - \frac{r}{\tilde{\pi} - \pi\left[(1-\theta_2^e)^2 + (\theta_2^e(1-\alpha))^2\right]}\ . \tag{6}$$

Combining the two first order conditions yields the expression,

$$\tilde{\pi} - [\tilde{\pi} + \pi - b](1 - \theta_2^e)^2 - \pi(1-\alpha)^2[\theta_2^e]^2 = 0, \tag{7}$$

which can be solved for the closed form expression of the entrants' equilibrium R&D intensity:

$$\tilde{\theta}_2^e = \frac{\tilde{\pi} + \pi - b - \sqrt{(\tilde{\pi} + \pi - b)^2 - [\pi - b]\,[\tilde{\pi} + \pi - b + \pi(1-\alpha)^2]}}{\tilde{\pi} + \pi - b + \pi(1-\alpha)^2}. \tag{8}$$

It is sometime useful to re-write the expression in the radical as

$$\sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]}. \tag{9}$$

We can now prove the statements described in section 2.2.1.Returning to the reaction functions, it is immediately obvious the one for the entrant is downard sloping. For the incumbent firm, the slope is

$$\frac{\partial \widehat{\theta}_2^i}{\partial \theta_2^e} = \frac{2r\pi\left(1 - \theta_2^e\left[1 + (1-\alpha)^2\right]\right)}{\tilde{\pi} - \pi\left[(1-\theta_2^e)^2 + (\theta_2^e(1-\alpha))^2\right]}. \tag{10}$$

Substituting (8) into the expression, the sign of (10) is the sign of

$$[1 + (1-\alpha)^2]\sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]} - [\tilde{\pi} - b](1-\alpha)^2 > 0.$$

Lemma 1 *The comparative statics for the reaction functions take the same sign as in the duopoly case.*

Proof. These are straightforward derivatives of (5) and (6), holding constant the R&D intensity of the firm's rival(s):

$$\frac{\partial \widehat{\theta}_2^e}{\partial r} = \frac{-1}{2\sqrt{r(1-\theta_2^i)[\tilde{\pi} \; - b]}} \qquad \frac{\partial \widehat{\theta}_2^i}{\partial r} = \frac{-1}{F}$$

$$\frac{\partial \widehat{\theta}_2^e}{\partial \pi} = 0 \qquad \frac{\partial \widehat{\theta}_2^i}{\partial \pi} = \frac{-r}{F}[(1-\theta_2^e)^2 + (\theta_2^e(1-\alpha))^2]$$

$$\frac{\partial \widehat{\theta}_2^e}{\partial \tilde{\pi}} = \frac{r}{2\sqrt{r(1-\theta_2^i)[\tilde{\pi} \; - b]^3}} \qquad \frac{\partial \widehat{\theta}_2^i}{\partial \tilde{\pi}} = \frac{r}{F^2}$$

$$\frac{\partial \widehat{\theta}_2^e}{\partial b} = \frac{-r}{2\sqrt{r(1-\theta_2^i)[\tilde{\pi} \; - b]^3}} \qquad \frac{\partial \widehat{\theta}_2^i}{\partial b} = 0$$

where $F \equiv \pi - \pi\left[(1-\theta_2^e)^2 + (\theta_2^e(1-\alpha))^2\right]$. ■

Lemma 2 *Changes in c that do not induce additional entry do not affect the R&D intensities of the active firms.*

Proof. This follows from the fact that c does not appear in (8) or directly in the reaction functions. But it appears in the participation constraint (see below). ■

Lemma 3 *The entrants individually do less R&D than in the duopoly case, but collectively they do more R&D. In other words, $\tilde{\theta}_2^e \leq \tilde{\theta}_1^e$ and $(1-\tilde{\theta}_2^e)^2 \leq (1-\tilde{\theta}_1^e)$.*

Proof. The first part is demonstrated more easily by comparing

$$(1-\tilde{\theta}_2^e) = \frac{\pi(1-\alpha)^2 + \sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]}}{\tilde{\pi} + \pi - b + \pi(1-\alpha)^2} \geq \frac{\tilde{\pi}}{\tilde{\pi} + \pi - b + \pi} = (1-\tilde{\theta}_1^e).$$

The second is demonstrated by rearranging terms in (7):

$$(1-\tilde{\theta}_2^e)^2 = \frac{\tilde{\pi} \;\; - \pi[\tilde{\theta}_2^e(1-\alpha)]^2}{\tilde{\pi} + \pi - b} \leq \frac{\tilde{\pi}}{\tilde{\pi} + \pi - b} = (1-\tilde{\theta}_1^e).$$

■

Lemma 4 *The incumbent does less R&D than in the duopoly case.*

Proof. Rearranging (4) yields the equality $(1-\tilde{\theta}_2^i)(1-\tilde{\theta}_2^e)^2 = r/(\tilde{\pi} - b)$. Substituting this expression into (3) yields

$$(1-\tilde{\theta}_2^i) = \frac{r\,[\tilde{\pi} + \pi - b]}{\tilde{\pi}\,[\tilde{\pi} - b]} + \frac{r\pi(1-\alpha)^2}{\tilde{\pi}\,[\tilde{\pi} - b]}\left(\frac{\tilde{\theta}_2^e}{1-\tilde{\theta}_2^e}\right)^2 = (1-\tilde{\theta}_1^i) + \frac{r\pi(1-\alpha)^2}{\tilde{\pi}\,[\tilde{\pi} - b]}\left(\frac{\tilde{\theta}_1^e}{1-\tilde{\theta}_1^e}\right)^2.$$

■

Lemma 5 *The comparative statics for the equilibrium R&D intensities take the same sign as in the duopoly case.*

Proof. We begin with the comparative statics for $\tilde{\theta}_2^e$:

$$\begin{aligned}
\frac{\partial\tilde{\theta}_2^e}{\partial r} &= 0, \\
\frac{\partial\tilde{\theta}_2^e}{\partial \pi} &= \frac{(1-\tilde{\theta}_2^e)^2 + (\tilde{\theta}_2^e(1-\alpha))^2}{2\sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]}} > 0, \\
\frac{\partial\tilde{\theta}_2^e}{\partial \tilde{\pi}} &= \frac{\tilde{\theta}_2^e\left([1 - 2\pi(1-\alpha)^2/\tilde{\pi}]\,\tilde{\theta}_2^e - 2\right)}{2\sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]}} < 0, \text{ and} \\
\frac{\partial\tilde{\theta}_2^e}{\partial b} &= \frac{2[\tilde{\theta}_2^e]^2(1-\alpha)\pi/\tilde{\pi} - (1-\tilde{\theta}_2^e)^2}{2\sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]}}.
\end{aligned}$$

Rearranging terms, the sign of the last derivative is negative where

$$\left(\frac{\tilde{\theta}_2^e}{1-\tilde{\theta}_2^e}\right)^2 \frac{\pi b}{\tilde{\pi}^2} \leq \frac{1}{2}.$$

Since $\partial\tilde{\theta}_2^e/\partial\pi > 0$, the left-hand-side of the previous expression is maximized at $\pi = \tilde{\pi}$, where it takes the value

$$\left(\frac{1+\alpha-\sqrt{1+\alpha^2(2-\alpha)}}{(1-\alpha)^2+\sqrt{1+\alpha^2(2-\alpha)}}\right)^2 (1-\alpha).$$

The maximum value of this expression is 0.03, when $\alpha \approx 0.62$.[16] Thus $\partial\tilde{\theta}_2^e/\partial\tilde{\pi} < 0$.The mixing probability α implies a value of marketing capital that is 38 percent of innovation size. In turn, this implies a maximum value of entrant R&D of $\tilde{\theta}_2^e \approx 0.29$.

For the comparative statics on $\tilde{\theta}_2^i$ we take derivatives of (6), taking into account the changes in $\tilde{\theta}_2^e$, just derived:

$$\begin{aligned}
\frac{\partial\tilde{\theta}_2^i}{\partial r} &= \frac{-1}{F} < 0 \\
\frac{\partial\tilde{\theta}_2^i}{\partial \pi} &= \frac{-rG}{F^2}\left(1-\frac{\pi(1-[1-(1-\alpha)^2]\tilde{\theta}_2^e)}{\sqrt{\tilde{\pi}^2+[\pi-b]\left[\tilde{\pi}-\pi(1-\alpha)^2\right]}}\right) < 0 \\
\frac{\partial\tilde{\theta}_2^i}{\partial \tilde{\pi}} &= \frac{2r}{F^2}\left(\frac{1}{2}+(\tilde{\theta}_2^e(1-\alpha))^2+\frac{\partial\tilde{\theta}_2^e}{\partial\tilde{\pi}}\left(1-\tilde{\theta}_2^e\left[1+(1-\alpha)^2\right]\right)\pi\right) > 0 \\
\frac{\partial\tilde{\theta}_2^i}{\partial b} &= \frac{-2r\pi}{F^2}\left(-\frac{\partial\tilde{\theta}_2^e}{\partial b}(1-\tilde{\theta}_2^e\left[1+(1-\alpha)^2\right])+\frac{1}{b}(\tilde{\theta}_2^e(1-\alpha))^2\right) < 0
\end{aligned}$$

where $F = \tilde{\pi} - \pi[(1-\tilde{\theta}_2^e)^2 + (\tilde{\theta}_2^e(1-\alpha))^2]$ and $G \equiv (1-\tilde{\theta}_2^e)^2 + (\tilde{\theta}_2^e(1-\alpha))^2$. For the last derivative, it is sufficient to show that $1+2\pi\partial\tilde{\theta}_2^e/\partial\tilde{\pi} > 0$. After substituting the comparative static for the entrant, this follows from the fact that $\sqrt{\tilde{\pi}^2+[\pi-b]\left[\tilde{\pi}-\pi(1-\alpha)^2\right]} > \pi[\tilde{\theta}_2^e]^2$. ■

Lemma 6 $V_2^i > V_1^i$ *and* $V_1^e > V_2^e$

Proof. Substituting the first order conditions back into the original value

[16]These numbers are derived using the NMaximize function in Mathematica.

functions:

$$\begin{aligned}
\frac{V_1^i}{r} &= \tilde{\pi} - r + Ln(1-\tilde{\theta}_1^i); \\
\frac{V_2^i}{r} &= \tilde{\pi} - r + Ln(1-\tilde{\theta}_2^i); \\
\frac{V_1^e}{r} &= \frac{\tilde{\theta}_1^e}{1-\tilde{\theta}_1^e} + Ln(1-\tilde{\theta}_1^e) - \frac{c}{r}; \quad \text{and} \\
\frac{V_2^e}{r} &= \frac{\tilde{\theta}_2^e}{1-\tilde{\theta}_2^e} + Ln(1-\tilde{\theta}_2^e) - \frac{c}{r}.
\end{aligned}$$

The incumbent's value function is clearly falling in $\tilde{\theta}^i$, and $\tilde{\theta}_2^i < \tilde{\theta}_1^i$. The second result follows from $\partial V^e/\partial\tilde{\theta}^e = \tilde{\theta}^e/(1-\tilde{\theta}^e)^2 > 0$ and $\tilde{\theta}_2^e < \tilde{\theta}_1^e$. ■

Corollary 7 *For increases in c that do not induce additional entry, the market value of the incumbent is unaffected, while the market value of an entrant declines.*

Lemma 8 *The comparative statics of the value functions are the same as in the duopoly case.*

Proof. These are straightforward derivatives. For the entrant:

$$\begin{aligned}
\frac{\partial V_2^e}{\partial r} &= \frac{\tilde{\theta}_2^e}{1-\tilde{\theta}_2^e} + Ln(1-\tilde{\theta}_2^e) > 0 & \frac{\partial V_2^e}{\partial \pi} &= \frac{r\tilde{\theta}_2^e}{(1-\tilde{\theta}_2^e)^2}\frac{\partial\tilde{\theta}_2^e}{\partial \pi} > 0 \\
\frac{\partial V_2^e}{\partial \tilde{\pi}} &= \frac{r\tilde{\theta}_2^e}{(1-\tilde{\theta}_2^e)^2}\frac{\partial\tilde{\theta}_2^e}{\partial \tilde{\pi}} < 0 & \frac{\partial V_2^e}{\partial b} &= \frac{r\tilde{\theta}_2^e}{(1-\tilde{\theta}_2^e)^2}\frac{\partial\tilde{\theta}_2^e}{\partial b} < 0
\end{aligned}$$

And for the incumbent:

$$\begin{aligned}
\frac{\partial V_2^i}{\partial r} &= Ln(1-\tilde{\theta}_2^i) - 1 - \frac{r}{1-\tilde{\theta}_2^i}\frac{\partial\tilde{\theta}_2^i}{\partial r} = Ln(1-\tilde{\theta}_2^i) < 0 \\
\frac{\partial V_2^i}{\partial \pi} &= -\frac{r}{1-\tilde{\theta}_2^i}\frac{\partial\tilde{\theta}_2^i}{\partial \pi} > 0 \\
\frac{\partial V_2^i}{\partial b} &= \frac{r}{1-\tilde{\theta}_2^i}\frac{\partial\tilde{\theta}_2^i}{\partial b} < 0
\end{aligned}$$

■

Corollary 9 *Reductions in the cost of marketing capital that do not induce additional entry raise the market value of the entrant, while reducing the market value of the incumbent.*

Lemma 10 *The set of parameter values (b, π) where two entrants engage in R&D is a strict subset of parameter space identified for an active entrant in the duopoly case.*

Proof. The partipation constraint for two entrants is defined by

$$\Psi \equiv V_2^e = \frac{r\tilde{\theta}_2^e}{1-\tilde{\theta}_2^e} + rLn(1-\tilde{\theta}_2^e) - c = 0.$$

Let $\hat{b}(\tilde{\pi}, \pi, r, c)$ denote the cost of marketing capital where the participation constraint just binds. It remains the case that, even if $c = 0$, no entrant will engage in R&D if $\tilde{\pi} - b - r \leq 0$. It is also true that the entrants will not engage in R&D if the incumbent is sufficiently active, which occurs where $\tilde{\theta}_2^i \geq 1 - r/[\tilde{\pi} - b]$. Substituting (8) into (6), we find that $\tilde{\theta}_2^i$ exceeds this value when $b > \pi\{(1-\tilde{\theta}_2^e)^2 + (\tilde{\theta}_2^e(1-\alpha))^2\}$. Recall that in the duopoly case, the relevant constraint for entry deterrence was that $b > \pi$.

Assuming $\partial\Psi/\partial\pi \neq 0$,we can u se the implicit function theorem to derive the slope of $\hat{b}(\tilde{\pi}, \pi, r, c)$.

$$\frac{\partial\Psi}{\partial\pi} = \frac{\tilde{\theta}_2^e}{(1-\tilde{\theta}_2^e)^2} \cdot \frac{(1-\tilde{\theta}_2^e)^2 + \tilde{\theta}_2^e(1-\alpha)^2}{2\sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]}} = \frac{\tilde{\theta}_2^e}{(1-\tilde{\theta}_2^e)^2} \cdot \frac{\partial\tilde{\theta}_2^e}{\partial\pi} > 0$$

and

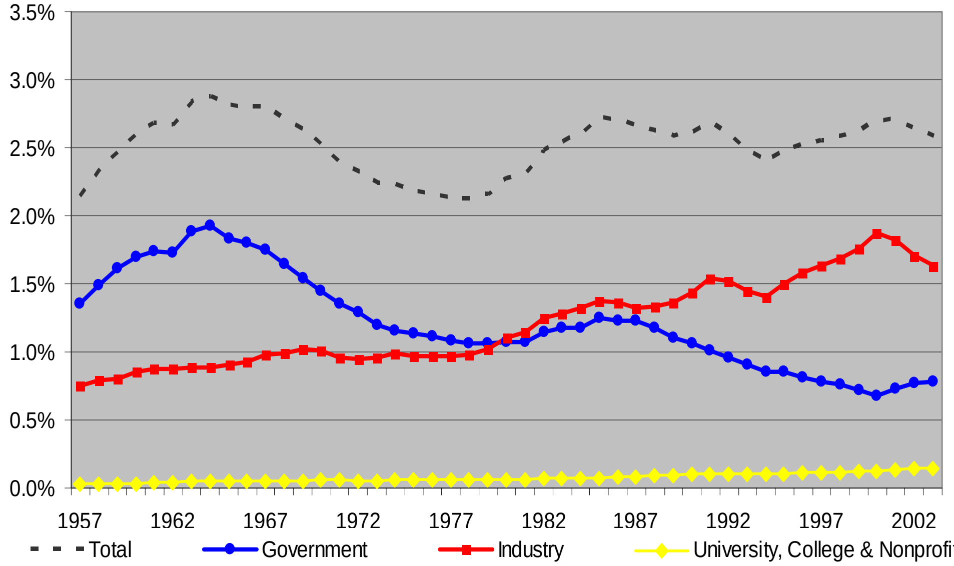
$$\frac{\partial\Psi}{\partial b} = \frac{\tilde{\theta}_2^e}{(1-\tilde{\theta}_2^e)^2} \cdot \frac{2\tilde{\theta}_2^e(1-\alpha)^2\pi/\tilde{\pi} - \left(1-\tilde{\theta}_2^e\right)^2}{2\sqrt{\tilde{\pi}^2 + [\pi - b]\,[\tilde{\pi} - \pi(1-\alpha)^2]}} = \frac{\tilde{\theta}_2^e}{(1-\tilde{\theta}_2^e)^2} \cdot \frac{\partial\tilde{\theta}_2^e}{\partial b}.$$

Thus

$$\frac{\partial\hat{b}}{\partial\pi} = \frac{(1-\tilde{\theta}_2^e)^2 - 2\tilde{\theta}_2^e(1-\alpha)^2\pi/\tilde{\pi}}{(1-\tilde{\theta}_2^e)^2 + \tilde{\theta}_2^e(1-\alpha)^2} \in [0,1].$$

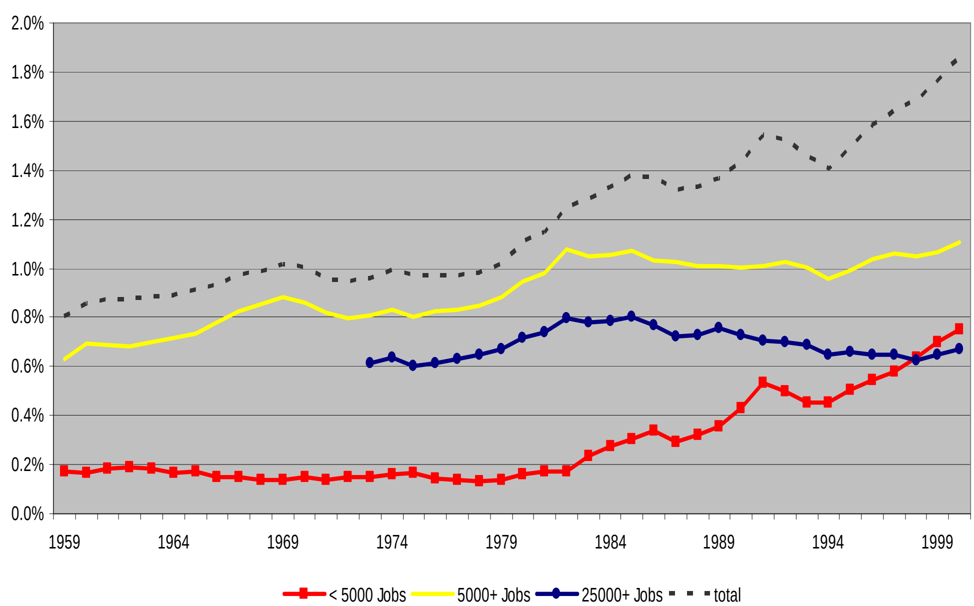
At $\pi = 0$, $\partial\hat{b}/\partial\pi = 1$. So we can conclude that $\hat{b}(\tilde{\pi}, \pi, r, c)$ lies below the participation for the entrant in the duopoly case, as illustrated in Figure 3, and it is strictly lower for values of $\pi < \tilde{\pi} - r$. Initially ($\pi = 0$) the slope of the two constraints are the same, but For $\pi > 0$, $\partial\hat{b}/\partial\pi < 1$, while the slope of the constraint in the duopoly case is 1 for values of $\pi < \tilde{\pi} - r$ and 0 thereafter. ■

Figure 1: R&D by Source of Funds, 1957-2003
(percent of GDP)



Source: National Science Foundation and authors' calculations

Figure 2: R&D by firm size
(percent of GDP)



Source: National Science Foundation and authors' calculations

Figure 3: State Space Diagram - Duopoly Case

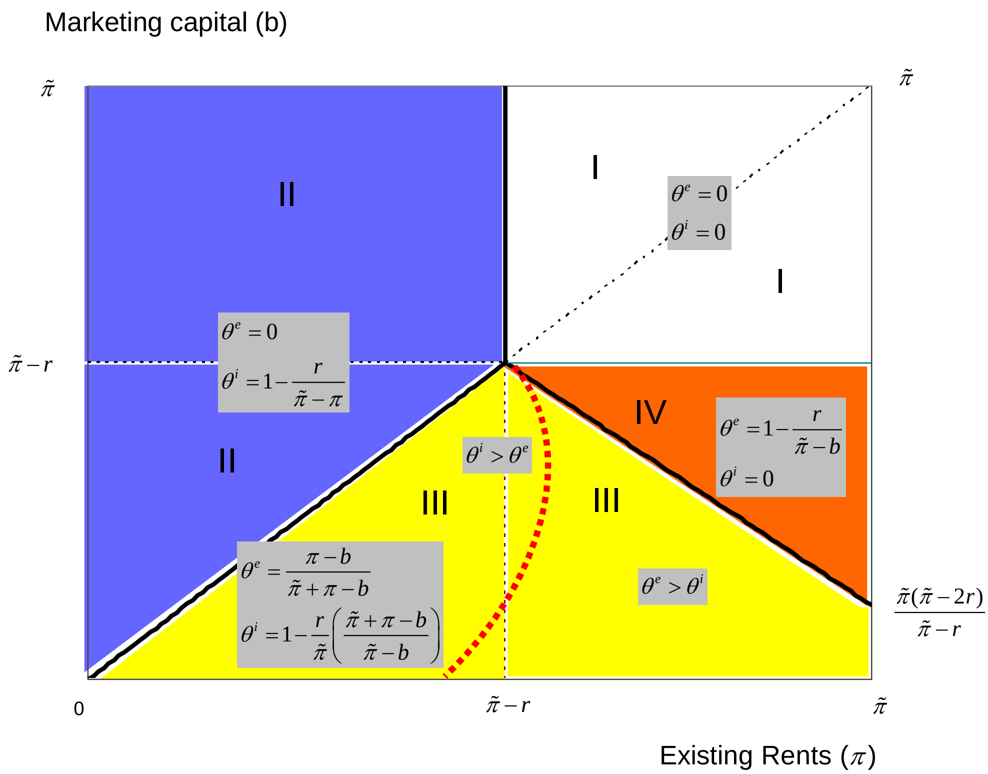
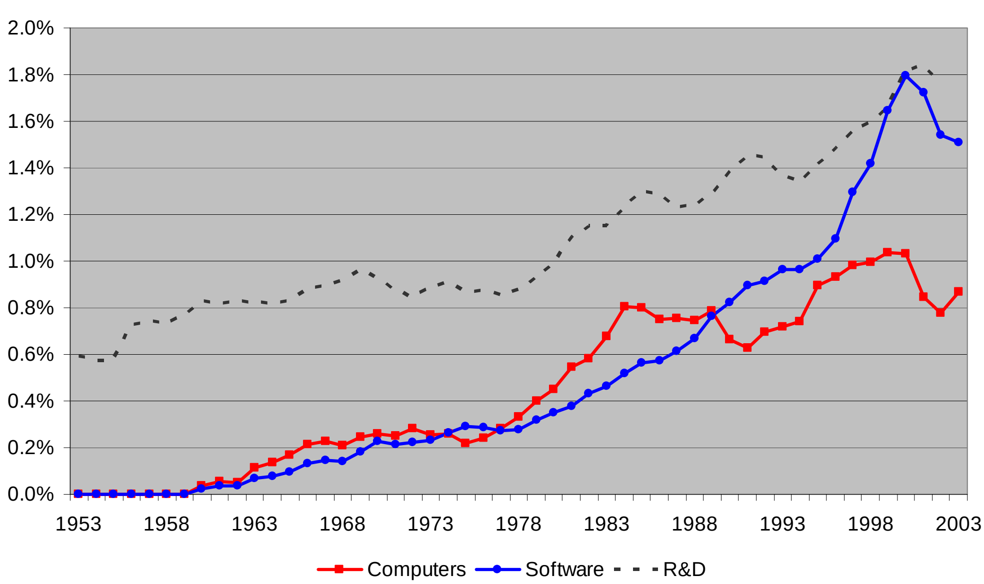


Figure 4: Investment in R&D, Computers, & Software
(Percent of GDP)



Source: Bureau of Economic Analysis, National Science Foundation, and authors' calculations.

Table 1: Testable Implications of the Model[†]				
	Change in Exogenous Parameter			
	↓ Marketing Capital (b)	↓ R&D Cost (r)	↑ Invention Size ($\tilde{\pi}$)	↑ Existing Rents (π)
R&D				
Incumbent	↑	↑	↑	↓
Entrant	↑	∅	↓	↑
Slope of R&D Reaction Function				
Incumbent	∅	↑	↑	↓
Entrant	↑	↑	↑	∅
Ex Ante Firm Value				
Incumbent	↓	↑	↑	↑
Entrant	↑	↓	↑	↑

[†]: For results for the case of entry by more than one firm, see section 2.2.1 and the Appendix.

Table 2: Incumbent Firms in R&D Industries

Company	Jobs, 1965	Company	Jobs, 1965
Alcoa Inc	48,200	Honeywell International Inc	36,600
American Cyanamid Co	34,100	Intl Business Machines Corp	172,445
American Home Products Corp	30,600	ITT Industries Inc	199,000
American Motors Corp	31,900	Litton Industries Inc	65,600
American Standard Cos Inc	37,200	Lockheed Martin Corp	81,300
Babcock & Wilcox Co	25,000	Martin Marietta Corp	30,000
Bendix Corp	46,500	McDonnell Douglas Corp	36,300
Bicoastal Corp	101,830	Motorola Inc	30,000
Boeing Co	93,400	Navistar International	111,980
Borg Warner Inc	35,850	NCR Corp	73,000
Caterpillar Inc	50,800	Olin Corp	43,000
CBS Corp	115,100	Otis Elevator Co	37,900
Celanese Corp	42,200	Owens-Illinois Inc	49,000
Chrysler Corp	166,800	Pfizer Inc	30,000
Colgate-Palmolive Co	26,200	Pharmacia Corp	56,200
Deere & Co	41,600	PPG Industries Inc	38,100
Dow Chemical	33,800	Procter & Gamble Co	35,300
Du Pont (E I) De Nemours	115,400	Raytheon Co	32,600
Eastman Kodak Co	55,500	RCA Corp	100,000
Eaton Corp	36,000	Revlon Group Inc	31,600
EMI Ltd	28,600	Reynolds Metals Co	30,300
Firestone Tire & Rubber Co	88,400	Rockwell Intl Corp	99,900
FMC Corp	37,600	Sperry Corp	93,600
Ford Motor Co	364,500	Texas Instruments Inc	34,500
Gencorp Inc	45,000	Textron Inc	41,000
General Dynamics Corp	84,600	TRW Inc	46,900
General Electric Co	257,900	Union Carbide Corp	73,900
General Motors Corp	735,000	Uniroyal Inc	65,000
Goodrich (B F) Co	43,900	Unisys Corp	35,200
Goodyear Tire & Rubber Co	103,700	United Technologies Corp	71,800
Grace (W R) & Co	53,400	Varity Corp	45,700
Grumman Corp	30,000	Viad Corp	32,400
Honeywell Inc	54,600		

Notes: Incumbent firms are those firms with at least 25,000 employees in 1965. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973.

Table 3: Distribution of R&D (Percent of Total)							
Year	Non-R&D Industries	Computer Industries		Non-computer Industries			
		Incumbent firms	Non-incumbent firms	Incumbent Industries			Non-incumbent Industries
				All firms	Incumbent firms	Non-incumbent firms	
1974	16.8	8.8	5.5	60.5	45.8	14.8	8.3
1979	17.3	8.2	7.3	59.6	45.0	14.5	7.5
1984	18.3	9.5	11.4	53.4	38.7	14.7	7.4
1989	15.7	10.3	14.8	52.7	38.8	13.9	6.5
1994	13.6	5.7	19.4	52.5	36.0	16.5	8.9
1999	7.6	4.7	26.3	47.6	30.0	17.6	13.8

Notes: Incumbent firms are those firms with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, and 737.

Table 4: R&D Intensity (R&D ÷ Operating Expense, percent)							
Year	Non-R&D Industries	Computer Industries		Non-computer Industries			
		Incumbent firms	Non-incumbent firms	Incumbent Industries			Non-incumbent Industries
				All firms	Incumbent firms	Non-incumbent firms	
1974	0.31	9.00	4.83	3.00	3.13	2.65	2.25
1979	0.31	8.00	6.05	2.99	3.17	2.56	2.42
1984	0.45	9.34	8.83	3.94	4.01	3.77	3.75
1989	0.46	10.00	9.81	4.29	4.30	4.26	3.28
1994	0.42	6.51	9.40	4.89	4.76	5.22	4.00
1999	0.28	7.48	10.25	5.63	5.35	6.17	5.71

Notes: Incumbent firms are those firms with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, and 737.

Table 5a: Statistics for Simple R&D Reaction Function Regressions (1973-97)

Variable:	All Firms	Computers	Non-computer Industries			
			Incumbent Industries			Non-incumbent Industries
			All Firms	Incumbent Firms	Other Firms	
$\left(\frac{R\&D}{OpExp}\right)_t^i$	0.0561 0.0285	0.0885 0.0379	0.0358 0.0223	0.0360 0.0146	0.0358 0.0232	0.0509 0.0257
$\left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	0.0575 0.0132	0.0893 0.0150	0.0392 0.0106	0.0338 0.0108	0.0400 0.0105	0.0512 0.0137
$Comp_t$	0.6544 0.1630	0.6994 0.1428	0.6108 0.1856	0.5852 0.2266	0.6145 0.1790	0.6584 0.1570
$comp_{t-1} * \left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	0.0392 0.0155	0.0630 0.0184	0.0247 0.0129	0.0202 0.0132	0.0253 0.0128	0.0352 0.0152
firms	4,029	1,273	989	60	929	1,767
observations	33,793	8,900	10,512	1,320	9,192	14,381
N.B.: R&D Expense (Pct., 1973)	100.0	26.5	64.0	46.3	17.7	9.5

Notes: Each cell includes the mean, followed by the within standard deviation. Statistics excludes observations with normalized market value (i.e., divided by operating expense) or the comparable measure for its rivals ≥ 14. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, or 737. Incumbent firms are companies with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. *Comp* is the ratio of computer investment to GDP, in nominal terms.

Table 5b: Statistics for Full R&D Reaction Function Regressions (1973-97)						
Variable:	All Firms	Computers	Non-computer Industries			
			Incumbent Industries			Non-incumbent Industries
			All Firms	Incumbent Firms	Other Firms	
$\left(\frac{R\&D}{OpExp}\right)_t^i$	0.0496 0.0232	0.0798 0.0285	0.0360 0.0214	0.0378 0.0151	0.0355 0.0226	0.0485 0.0219
$\left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	0.0477 0.0127	0.0782 0.0144	0.0362 0.0113	0.0347 0.0111	0.0366 0.0113	0.0444 0.0131
$Comp_t$	0.5873 0.1931	0.6228 0.1786	0.5752 0.2036	0.5866 0.2271	0.5726 0.1981	0.5823 0.1893
$comp_{t-1} * \left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	0.0292 0.0156	0.0490 0.0192	0.0214 0.0137	0.0208 0.0134	0.0215 0.0137	0.0273 0.0154
$\left(\frac{Patents}{OpExp}\right)_{t-1}^i$	0.1187 0.2083	0.1029 0.1024	0.0906 0.1698	0.0700 0.0288	0.0951 0.1871	0.1533 0.2702
$Comp_{t-1} * \left(\frac{Patents}{OpExp}\right)_{t-1}^i$	0.0669 0.0937	0.0605 0.0638	0.0483 0.0806	0.0396 0.0245	0.0501 0.0883	0.0880 0.1148
$\left(\frac{Patents}{OpExp}\right)_{t-1}^{\sim i}$	0.0718 0.0276	0.0817 0.0349	0.0605 0.0190	0.0582 0.0236	0.0609 0.0179	0.0781 0.0306
$Comp_{t-1} * \left(\frac{Patents}{OpExp}\right)_{t-1}^{\sim i}$	0.0403 0.0206	0.0489 0.0282	0.0327 0.0137	0.0318 0.0143	0.0329 0.0136	0.0435 0.0218
firms	1,246	257	450	55	395	539
observations	17,244	3,351	6,814	1,229	5,585	7,079
N.B.: R&D Expense (Pct., 1973)	100.0	23.5	68.0	49.9	18.2	8.5

Notes: Each cell includes the mean, followed by the within standard deviation. Statistics exclude observations with normalized market value (i.e., divided by operating expense) or the comparable measure for its rivals ≥ 14. Also excluded are observations where firms are not matched to their patents in the NBER Patent Citations Data File. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, or 737. Incumbent firms are companies with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. *Comp* is the ratio of computer investment to GDP, in nominal terms.

Table 6: Simple Reaction Function Regressions with Fixed and Year Effects
(R&D Industries, 1973-97)

Dependent Variable:	All Firms	Computers	Non-computer Industries			
			Incumbent Industries			Non-incumbent Industries
$\left(\frac{R\&D}{OpExp}\right)_t^i$			All Firms	Incumbent Firms	Other Firms	
constant	0.0524 0.0015 0.0000	0.0784 0.0055 0.0000	0.0221 0.0018 0.0000	0.0232 0.0023 0.0000	0.0224 0.0021 0.0000	0.0542 0.0019 0.0000
$\left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	-0.1868 0.0333 0.0000	-0.0803 0.0895 0.3693	0.0548 0.0557 0.3253	0.0284 0.0816 0.7275	0.0433 0.0632 0.4935	-0.2857 0.0483 0.0000
$Comp_{t-1} * \left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	0.3964 0.0357 0.0000	0.3418 0.0986 0.0005	0.5734 0.0580 0.0000	0.8277 0.0916 0.0000	0.5640 0.0653 0.0000	0.3021 0.0530 0.0000
n	33,793	8,900	10,512	1,320	9,192	14,381
Within R^2	.0263	.0251	.1034	.3857	.0898	.0172

Notes: 1st row is the coefficient; 2nd is the standard error; 3rd is the *p* value. Regression exclude observations with normalized market value (i.e., divided by operating expense) or the comparable measure for its rivals ≥ 14. R&D industries are those with R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, or 737. Incumbent firms are companies with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. *Comp* is the ratio of computer investment to GDP, in nominal terms.

Table 7: Full Reaction Function Regressions with Fixed and Year Effects
(R&D Industries, 1973-97)

Dependent Variable:	All Firms	Computers	Non-computer Industries			
$\left(\frac{R\&D}{OpExp}\right)_t^i$			Incumbent Industries			Non-incumbent Industries
			All Firms	Incumbent Firms	Other Firms	
constant	0.0482	0.0810	0.0236	0.0273	0.0242	0.0612
	0.0016	0.0058	0.0021	0.0029	0.0026	0.0025
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$\left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	-0.1015	-0.2429	0.0820	-0.0213	0.1080	-0.2330
	0.0394	0.1223	0.0764	0.0949	0.0952	0.0592
	0.0100	0.0472	0.2833	0.8220	0.2567	0.0001
$Comp_{t-1}*\left(\frac{R\&D}{OpExp}\right)_{t-1}^{\sim i}$	0.4271	0.5493	0.6356	1.0326	0.5723	0.3187
	0.0439	0.1633	0.0859	0.1123	0.1066	0.0649
	0.0000	0.0008	0.0000	0.0000	0.0000	0.0000
$\left(\frac{Patents}{OpExp}\right)_{t-1}^{i}$	0.0007	-0.0137	0.0032	-0.1034	0.0037	-0.0006
	0.0013	0.0104	0.0029	0.0222	0.0031	0.0014
	0.5856	0.1893	0.2733	0.0000	0.2432	0.6574
$Comp_{t-1}*\left(\frac{Patents}{OpExp}\right)_{t-1}^{i}$	0.0151	0.0618	0.0446	0.1739	0.0437	-0.0013
	0.0029	0.0171	0.0061	0.0317	0.0066	0.0033
	0.0000	0.0003	0.0000	0.0000	0.0000	0.6987
$\left(\frac{Patents}{OpExp}\right)_{t-1}^{\sim i}$	-0.0556	-0.0095	-0.0147	0.1229	-0.0408	-0.1346
	0.0135	0.0332	0.0238	0.0288	0.0314	0.0231
	0.0000	0.7752	0.5357	0.0000	0.1939	0.0000
$Comp_{t-1}*\left(\frac{Patents}{OpExp}\right)_{t-1}^{\sim i}$	0.0323	-0.0420	-0.0868	-0.3569	-0.0503	0.1774
	0.0192	0.0487	0.0353	0.0505	0.0445	0.0342
	0.0932	0.3883	0.0140	0.0000	0.2584	0.0000
n	17, 244	3,351	6,814	1,229	5,585	7,079
Within R^2	.0731	.0668	.1874	.4275	.1690	.0485

Notes: 1st row is the coefficient; 2nd is the standard error; 3rd is the *p* value. Regression excludes observations with normalized market value (i.e., divided by operating expense) or the comparable measure for its rivals ≥ 14. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, or 737. Incumbent firms are companies with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. *Comp* is the ratio of computer investment to GDP, in nominal terms.

Table 8: Descriptive Statistics for Market Value Regressions with Heckman Selection Correction on demeaned variables (R&D Industries, 1973-97)						
Dependent Variable:	All Firms	Computer Industries	Non-computer industries			
			Incumbent Industries			Non-incumbent Industries
			All Firms	Incumbent Firms	Other Firms	
$\left(\frac{MV}{OpExp}\right)_t^i$	1.1540 0.9463	1.4066 1.1765	0.9847 0.8196	0.6907 0.5243	1.0506 0.8722	1.1938 0.9346
$comp_t$	0.5891 0.1933	0.6213 0.1790	0.5778 0.2040	0.5875 0.2276	0.5756 0.1984	0.5843 0.1894
$\left(\frac{BV}{OpExp}\right)_t^i$	0.5395 0.2073	0.5997 0.2353	0.4791 0.1906	0.3870 0.1068	0.4997 0.2048	0.5683 0.2083
$Comp_t * \left(\frac{BV}{OpExp}\right)_t^i$	0.3288 0.1846	0.3876 0.2027	0.2832 0.1743	0.2244 0.1104	0.2964 0.1856	0.3439 0.1851
$\left(\frac{R\&D}{OpExp}\right)_t^i$	0.0507 0.0244	0.0807 0.0286	0.0369 0.0243	0.0380 0.0151	0.0367 0.0259	0.0494 0.0222
$Comp_t * \left(\frac{R\&D}{OpExp}\right)_t^i$	0.0327 0.0223	0.0534 0.0272	0.0231 0.0212	0.0239 0.0170	0.0230 0.0220	0.0319 0.0207
$\left(\frac{Patents}{OpExp}\right)_{t-1}^{\sim i}$	0.1220 0.2218	0.1027 0.1044	0.0918 0.1842	0.0699 0.0283	0.0967 0.2034	0.1604 0.2871
$Comp_{t-1} * \left(\frac{Patents}{OpExp}\right)_{t-1}^{\sim i}$	0.0691 0.1056	0.0606 0.0652	0.0493 0.0918	0.0396 0.0240	0.0515 0.1009	0.0923 0.1308
firms	1,189	251	421	54	367	517
observations	16,941	3,364	6,652	1,218	5,434	6,925

Notes: 1st row is the coefficient; 2nd is the standard error; 3rd is the *p* value. These statistics exclude observations for firms not matched to their patents in the NBER Patent Citations Data File. Also excluded are observations with normalized market value (i.e., divided by operating expense) ≥ 14 or missing, normalized book value ≥ 4 or normalized book value ≤ -0.1. Market and book variables are year-end values. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, or 737. Incumbent firms are companies with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. *Comp* is the ratio of computer investment to GDP, in nominal terms.

Table 9: Full Market Value Regressions with Heckman Selection Correction (on demeaned variables)
(R&D Industries, 1973-97)

Dependent Variable:	All Firms	Computer Industries	Non-computer industries			
			Incumbent Industries			Non-incumbent Industries
$\left(\frac{MV}{OpExp}\right)_t^i$			All Firms	Incumbent Firms	Other Firms	
time	-0.0021	-0.0476	0.0230	0.0366	0.0177	-0.0052
	0.0023	0.0060	0.0032	0.0042	0.0038	0.0037
	0.3658	0.0000	0.0000	0.0000	0.0000	0.1651
$Comp_t$	0.6822	1.8697	-0.0582	-0.2829	0.0061	0.6936
	0.0905	0.2591	0.1176	0.1824	0.1385	0.1486
	0.0000	0.0000	0.6208	0.1209	0.9646	0.0000
$\left(\frac{BV}{OpExp}\right)_t^i$	2.3136	3.3726	1.5852	2.2557	1.4999	2.4693
	0.0904	0.2390	0.1255	0.2594	0.1407	0.1423
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$Comp_t * \left(\frac{BV}{OpExp}\right)_t^i$	-0.6058	-1.1368	-0.0820	-1.4304	0.0564	-1.0347
	0.1216	0.3247	0.1659	0.3625	0.1863	0.1933
	0.0000	0.0005	0.6212	0.0001	0.7619	0.0000
$\left(\frac{R\&D}{OpExp}\right)_t^i$	2.908	2.9630	-0.1842	-1.3499	0.2824	0.2412
	0.6501	1.5340	1.0325	2.1197	1.1556	1.0305
	0.0000	0.0534	0.8584	0.5242	0.8070	0.8145
$Comp_t * \left(\frac{R\&D}{OpExp}\right)_t^i$	-1.1289	-5.8368	5.9401	17.4680	4.4879	2.0774
	0.8132	1.9372	1.3340	2.5420	1.5036	1.2663
	0.1651	0.0026	0.0000	0.0000	0.0028	0.1009
$\left(\frac{Patents}{OpExp}\right)_{t-1}^{\sim i}$	-0.3062	2.0126	-0.0234	3.3717	-1.3809	-0.8608
	0.2480	0.5082	0.5297	0.6124	0.6631	0.3581
	0.2170	0.0001	0.9648	0.0000	0.0373	0.0162
firms	4,334	1,442	1,006	59	947	1,886
matched to patents	1,189	251	421	54	367	517
observations	35,688	9,838	10,620	1,307	9,313	15,230
Wald Statistic	3,999	1,539	1,631	705	1,273	1,366

Notes: 1st row is the coefficient; 2nd is the standard error; 3rd is the *p* value. The first stage regression predicts the likelihood that a firm is matched to its patents in the NBER Patent Citations Data File. The right-hand-side variables include the log of assets, a dummy for young firms, and year dummies. The second stage regression (reported here) includes the resulting selection correction and a constant. Market and book variables are year-end values. R&D industries are defined as industries where R&D/Sales ≥ 1 in 1973. Computer industries include firms in SICs 357, 367, or 737. Incumbent firms are companies with at least 25,000 employees in 1965. Incumbent industries are those SICs with at least one incumbent firm. *Comp* is the ratio of computer investment to GDP, in nominal terms. Excludes observations with normalized market value (i.e., divided by operating expense) ≥ 14 or missing, normalized book value ≥ 4 or normalized book value ≤ -0.1.