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R&D TAX POLICY DURING THE 1980s: SUCCESS OR FAILURE?

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EXECUTIVE SUMMARY

R&D tax policy in the United States during the nineteen-eighties is evaluated, with particular emphasis placed on quantifying the impact of the R&D tax credit on the R&D investment of manufacturing firms. Using publicly available data on R&D spending at the firm level, I estimate an average tax price elasticity for R&D spending which is in the neighborhood of unity in the short run. Although the effective credit rate is small (less than five percent until 1990), this relatively strong price response means that the amount of additional R&D spending thus induced was greater than the cost in foregone tax revenue. The recent evolution of features of the U.S. corporate tax system which affect R&D is also reviewed and my results are compared with those of previous researchers.

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The conclusion is that the R&D tax credit seems to have had the intended effect, although it took several years for firms to fully adjust. I also argue that although the high correlation over time of R&D spending at the firm level makes it difficult to estimate long run effects precisely, the same high correlation makes it probable that these effects are large.

I. INTRODUCTION

For at least the past twenty or thirty years, the tax policy of the U.S. government toward Research and Development (R&D) spending by private industrial firms has been designed to subsidize these expenditures at a rate that has varied over time. There are several features of the tax code that contribute to this policy: first, most R&D expenditures can be expensed as they are incurred,[1] which implies a faster write-off than the economic depreciation of the capital created by these expenditures.[2] Second, since the Economic Recovery Tax Act of 1981, a Research and Experimentation tax credit has been available to firms that increase their expenditures beyond some base level. Third, and somewhat more obscurely, Hines (1992) has shown that to the extent that R&D can be directed toward sales in foreign countries, there is an implicit subsidy to this activity arising from the interaction of the U.S. tax system with that of most foreign countries.

How large are these subsidies in practice, and do they have the desired effect of promoting socially valuable R&D spending? Are they worth the lost tax revenue? Various authors have attempted answers to these questions, sparked by the new tax credits of the early 1980s; most have concluded that the tax credit, at least, has had a relatively minor effect on the R&D spending of U.S. corporations, at least until about 1985.[3] Eisner, Albert, and Sullivan (1984) state, "We have as yet been

[1] Since 1954, under section 174 of the Internal Revenue code, a taxpayer may elect either to deduct or to amortize over sixty months or more the amount of research and experimental expenditures incurred in connection with its trade or business (U.S. Congress Committee on Finance Report, 1986). In practice most firms expense R&D. The definition of R&D in this part of the regulations is not spelled out in the code but has been interpreted by the Treasury to mean "research and development costs in the experimental or laboratory sense."

[2] See Griliches (1979), Pakes and Schankerman (1984), and Hall (1990b) for evidence on the private economic depreciation rate of R&D.

[3] See Eisner, Albert, and Sullivan (1984), Mansfield (1986), Altshuler (1988), and the GAO Report (1989) for studies of the impact of the Research and Experimentation Credit on R&D spending in the early 1980s. All of these studies use data only from the first half of the 1980s, and none of them evaluate the effects of the tinkering with the credit that occurred later in the period. Eisner, Albert and Sullivan (1984) study 592 firms from 1980 to 1982,

unable to detect reliable evidence of a positive impact of the credit on total R&D expenditures." Altshuler (1988) finds that the average ex-ante marginal credit rate is 1.3 percent in 1981 (2.3 percent when weighted by qualified research expenditures) and concludes that with asymmetric taxation and credit carryforwards, "the incentive effects of the credit are reduced even further leading us (*sic*) to question the logic of retaining the credit in its current form." A General Accounting Office study (1989) combines estimates of the effective credit rate (3–5 percent) with an assumed R&D price elasticity of −0.2 to −0.5 to conclude that the credit induced somewhere in the range of $0.2–0.5 billion of research spending per year from 1981 through 1985, which is about 1 percent of total private industrial R&D spending.

In spite of this evidence, the President, some members of Congress, and many high-technology industrial organizations continue to press for a permanent Research and Experimentation (R&E) tax credit, which suggests that the question of its effect is worth reexamination using the almost ten years of history now available to us. There are several other reasons why this topic is worth further study now: the first is that the tax credit was changed in significant ways since the previous work was done, particularly in 1990, when the computation of the base level of R&D was completely altered; this change raised the effective credit rate and, thus, should have increased the response of firms.

However, a more important reason for undertaking the study reported here is the opportunity to study the price responsiveness of R&D, which the data now provide us. The results reported earlier (Altshuler, 1988; Eisner, Albert, and Sullivan, 1984; and the 1989 GAO study) did not estimate a behavioral response of R&D to tax price changes, but merely inferred changes based on price elasticities measured using aggregate data or, in some cases, panel data sets. The best estimates of the price elasticity of R&D capital at the firm level are probably those of Bernstein and Nadiri (1988), which are based on a sample of thirty-five firms in four two-digit industries for eight years from 1959 to 1966. But because the firms effectively all face the same "price" of R&D, identifica-

which account for about 80 percent of private industrial R&D during the period; they make use of Compustat data and a privately conducted McGraw-Hill survey as well as OTA tabulations of R&D tax credit returns for 1981. Altshuler uses 5042 nonfinancial public corporations with assets greater than $10 million (1982 dollars) from 1977 to 1984, again covering around 80 percent of R&D. The actual data here come from the Treasury Department's Corporate Tax Model, which samples corporate tax returns annually. The GAO study uses 800 nonfinancial corporations from roughly the same source for 1981–1985; the firms in their sample are considerably larger on average than Altshuler's (assets greater than $250 million [1982 dollars]), but they cover only a slightly smaller amount of total R&D expenditure.

tion of the price elasticity comes from eight years of price data and the functional form of the model. Given this, it is reassuring that they obtain essentially the same number for the long-run price elasticity in all four industries, −0.5.

Other estimates are those of Mansfield (1986), who cites −0.35 as an R&D price elasticity, apparently obtaining the estimate from Mohnen, Nadiri, and Prucha (1986)[4], and Baily and Lawrence (1987, 1992), who obtain estimates on the order of −1.0, using aggregate and industry level data and a dummy for the tax credit. Given the fact that the only measurable variation in the cost of performing R&D is over time, it is extremely difficult to convince oneself of the reliability of estimates based solely on cost. Thus, the advantage of the R&E tax credit and the many variations in its history is the cross-sectional variability that it provides us as researchers in the key price variable, creating a natural experiment in which we can measure the response of R&D investment to changes in its cost. Among the prior studies of the price elasticity of R&D described, only those by Baily and Lawrence[5] attempt to take advantage of this variability; although their results are not without interest, their approach is the somewhat crude one of including a dummy variable for the credit years in an equation computed at the aggregate two-digit industry level. Thus, it seems worth reexamining the R&E tax credit question with firm level data, both to improve on earlier price elasticity estimates, and to evaluate the tax credit itself, particularly for the second half of the 1980s.

[4] Although Mansfield refers to this as an R&D spending elasticity, the Mohnen, Nadiri, and Prucha estimate is in fact an R&D capital elasticity, as was the Bernstein and Nadiri (1988) estimate. The two will coincide in the long run if R&D spending is a constant fraction of R&D capital and the firms are in a long run steady state; this is unlikely to be a realistic description of this sample. In the short run, the R&D spending elasticity will be quite a bit higher than the R&D capital elasticity, about five times as high for a typical firm in this sample. This means that the Bernstein and Nadiri and Mohnen, Nadiri, and Prucha estimates must be converted to about −2 before they can be compared with my estimates or those of Hines (1992) or Baily and Lawrence (1987, 1992). I am grateful to Jeffrey Bernstein for pointing this out to me.

[5] After this paper was written, I became aware of an unpublished study by Berger (1992) that uses individual firm-level data and the dummy variable technique of Baily and Lawrence to evaluate the R&D tax credit. Although the sample selection problem in this study is severe (it is restricted to the 263 firms in my sample who have R&D spending and other data continuously from 1975 to 1989), it does find results similar to mine. From the Berger estimates of the differences in mean R&D intensity for firms who can and cannot use the credit and my computation of effective credit rates during the period, it is possible to compute an average implied price elasticity: the estimates range from −1.0 to −1.5 throughout the 1981–1989 period, which is entirely consistent with my results. Berger, like me, finds that the R&E tax credit was cost-effective, in the sense that it induced more R&D spending than the lost tax revenue.

The present paper addresses itself to this problem. It begins with a brief description of R&D tax policy during the recent past, emphasizing the details of the R&E tax credit. This is followed by the description of a simple investment model that provides a framework for analyzing the response of firms to the tax credit. Tables and a figure showing the effective credit rates, their dispersion, and estimated revenue cost of the credit during the 1980s are then presented. Finally, I use a newly updated database of publicly traded manufacturing firms from Compustat to estimate the tax price responsiveness of R&D investment spending during the 1980s and answer the questions posed earlier.

Why should government have an R&D tax policy, and how should we judge its effectiveness? Beginning with Arrow (1962), a large number of authors have argued that industrial R&D exhibits a classic public goods problem, in that it is both nonrivalrous and not completely excludable (except to the extent that trade secrets, patents, lead time, and other methods of appropriability are successful). Empirical studies (summarized in Griliches, 1991) have confirmed this, finding social rates of return to R&D in both industry and agriculture that are far in excess of measured private rates of return.[6] If true, this result implies that private R&D investment has positive externalities, and an insufficient amount will be performed given competitive markets.[7] The classical public finance solution to such a problem is a subsidy to the activity that generates the positive externality, a subsidy designed to raise the private rate of return to the activity to the social level.[8] This is clearly the primary justification for the form of R&D tax policy in the United States.

But what would be the *optimal* subsidy to this activity, and how would we measure it? In principle, we would like to subsidize the price of R&D

[6] Other researchers (e.g., Dasgupta and Stiglitz, 1980) have argued from economic theory that the patent system or other appropriability mechanisms may lead to overinvestment in R&D in some cases, but the empirical evidence cited by Griliches is overwhelmingly in favor of the underinvestment hypothesis.

[7] Note that even if markets are imperfectly competitive (as they almost surely are for R&D-intensive firms, because of the high fixed-cost component in their production function), the fact that measured social and private rates of return differ is sufficient to conclude that the socially optimal level of R&D is not being performed.

[8] Of course, other solutions to the problem also exist, but again, the measured divergence in rates of return suggests that they are imperfect. These methods also typically have the defect of making the industries affected even more imperfectly competitive than they already are. The most obvious is the patent system, which attempts to increase the appropriability of technological innovations. Another method is to allow joint ventures in R&D in order to internalize the externality *a la* Coase. Either of these solutions clearly creates a monopoly in a particular product to the extent that they are successful, so that they involve the usual uncertain trade-off between the output restrictions caused by monopoly power and more efficient production of innovations.

in such a way as to make the private rate of return equal to the social rate of return at the socially optimal level of R&D spending. This is shown in stylized fashion in Figure 1, where the two curves that slope downward to the right represent the private and social marginal products of R&D investment, respectively. The upward-sloping curve is the required rate of return to R&D investment, which is assumed to increase in the level of R&D performed because of the heterogeneity of projects available and risk considerations. Note that the simplifying assumption that the cost of capital signaled by the investment community is a good reflection of society's willingness to pay has been made in locating the social optimum on this curve.

The problems with actually implementing a tax subsidy to move firms from R_C to R_S are several: first, the gap between social and private rates of return will vary by industry because of the difference in appropriability conditions (see Levin et al. (1989) for survey results by industry). Second, how do we measure the gap at the optimal level of R? If we knew the social optimum and the price elasticity of R&D expenditure, we could calculate how much reduction in price would be necessary to elicit the appropriate increase in quantity. But it is much more likely that we have some idea of the rate of return gap at the current quasi-competitive outcome (C), from which we will have to derive the subsidy required to

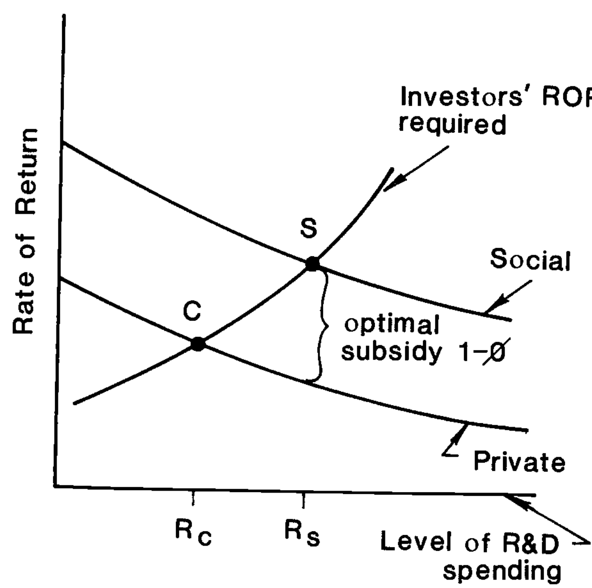

FIGURE 1. *The Optimal Subsidy to R&D.*

get to S. Because even this is quite difficult, most analysts have fallen back on a kind of cost benefit analysis: how does the R&D induced by a tax subsidy compare with the tax revenue cost of the subsidy? After presenting estimates of the induced R&D, I will attempt to answer at least this simpler question.

II. A BRIEF HISTORY OF THE R&D TAX CREDIT

The R&E tax credit as it has been implemented during the 1980s is a good example of how even a simple public policy idea that has bipartisan support can emerge from Congress both greatly complicated and weakened in its effects. In the case of the tax credit, the major problems are twofold: first, the need for tax revenue caused it to be greatly diluted in an attempt to focus the effects on the marginal R&D dollar, and second, indecision and lack of agreement on the part of legislators has led to repeated tinkering with and temporary extension of the credit from year to year, rather than a permanent credit that would last at least as long as the typical planning horizon for R&D investment.

A brief summary of the history of R&D tax policy in the United States during the 1980s follows. This policy has had three ingredients: (1) the expensing rules for Research and Development in general (section 174), which have remained essentially unchanged from earlier periods; (2) the R&E tax credit; and (3) the foreign source income allocation rules for R&D, which were changed repeatedly during the 1980s. The first of these policies can be summarized briefly as allowing the expensing of most R&D expenditures against corporate income for tax purposes. The reduction of the corporate tax rate during the 1980s had a substantial impact on the cost of an R&D dollar, because it reduced the benefit of expensing (*relative* to other types of capital investment) by the fall in the tax rate (a reduction of 0.12 for firms with taxable income, possibly more if they face the alternative minimum tax of 20 percent). Note that if a firm undertaking R&D investment faces the same corporate tax rate in all periods, the corporate tax rate is irrelevant to that investment, because the firm spends after-tax dollars on the investment and receives after-tax dollars as income. However, if the tax rate is changing for one reason or another, or the firm is moving in and out of taxable status, the changes in rate will begin to affect the cost of R&D capital faced by the firm (Fullerton and Lyon, 1988; Hall, 1991). For this reason, I have explicitly incorporated a changing corporate tax rate in the model and estimation presented later in the paper.

The R&E tax credit was introduced in the Economic Recovery Tax Act of 1981; it was originally scheduled to be effective from July 1, 1981, to

December 31, 1985. The credit was renewed for two years (January 1, 1986, to December 31, 1988) in a somewhat reduced form by the Tax Reform Act of 1986, and extended for one year through 1989 by the Technical and Miscellaneous Revenue Act of 1988. The Omnibus Budget Reconciliation Act of 1989 effectively extended the credit through 1990, and The Omnibus Budget Reconciliation Act of 1990 did the same for 1991. The Tax Extension Act of 1991 extended the credit through June 30, 1992. Most of these pieces of legislation also made changes to the terms of the credit.[9]

In all cases, the R&E tax credit is computed by taking qualified R&D expenditures that exceed a certain base level, multiplying by the statutory credit rate, and deducting this amount from corporate income taxes. There is a three-year carryback and fifteen-year carryforward in the case of no taxable income in the current year. After 1989, the credit also reduces the R&D expenditure available for deduction from current income under the old section 174 rules. A summary of the changes in the credit rate, qualified expenditure rules, base levels, and corporate income tax rates during the 1980s is shown in Table 1.[10]

In the next section of the paper, I present estimates of the average effective marginal rates of tax credit for U.S. manufacturing firms. These estimates make it clear that although the statutory rate has been between 25 and 20 percent for much of the history of the R&E tax credit, the actual rate has hovered around 4 percent, and only in the last two years does it rise above 5 percent. As previous researchers have pointed out, the primary source of this shortfall is the rolling base level of R&D,

[9] From the perspective of a researcher on this topic, one of the most important changes occurred in 1986, when the Tax Reform Act rolled the R&D tax credit into the General Business Credit and subjected it to the General Business Credit limitations. This both makes it more difficult to calculate the effective credit rate from public data, and simultaneously removed the R&D tax credit as a separate line item in the *Statistics on Income*. It is still shown in one of the tables for the whole corporate sector, but we no longer have the industrial detail that was available through 1985.

[10] Another feature of the Tax Reform Act of 1986 that affected R&D incentives was the strengthening of the alternative minimum tax (AMT) system for corporations. If a firm is subject to AMT, it cannot claim the R&D tax credit in the current year, but must carry it forward (for up to fifteen years) until it is subject to regular corporate tax. Also, the rate of taxation under AMT is 20% rather than the statutory corporate rate of 34%. As Lyon (1991) has discussed, this means that firms that are *temporarily* subject to the AMT will face tax incentives that are slightly tilted away from investment in intangibles toward tangibles, relative to what they would face under ordinary corporate taxation. In practice, only a small number of large manufacturing firms in 1988 filed AMT returns, accounting for only 3 percent of the total tax bill paid by manufacturing firms (*Statistics on Income*, 1988), so this is unlikely to be important. However, the reduction in the implicit subsidy to R&D that the AMT creates is likely to be more important in recession years, when corporate profits are down. This may account for some of the reduced nominal R&D spending that we observe in 1990 and 1991. Unfortunately, the data that would allow us to assess this likelihood are not yet available from the IRS.

TABLE 1.
History of R&D Tax Treatment 1981–1991.

Period	Credit Rate	Corporate Tax Rate	Definition of Base	Qualified Expenditures	Sect. 174 Deduction?	Foreign Allocation Rules
Jul 1981 to Dec 1985	0.25	0.46 (0.48 in 1981)	Max of previous 3-year average or 50% of current year	Excluded: Res. done outside U.S.; Humanities & Social Sciences; Research funded by others.	None	100% deduction against domestic income
Jan 1986 to Dec 1986	0.20	0.34	same	Narrowed def. to "technological" research. Exclude leasing.	None	same
Jan 1987 to Dec 1987	0.20	0.34	same	same	None	50% deduction against domestic income 50% allocation
Jan 1988 to Apr 1988	0.20	0.34	same	same	None	64% deduction against domestic income 36% allocation
May 1988 to Dec 1988	0.20	0.34	same	same	None	30% deduction against domestic income 70% allocation
Jan 1989 to Dec 1989	0.20	0.34	same	same	Subtract 50% of credit	64% deduction against domestic income 36% allocation
Jan 1990 to Dec 1991	0.20	0.34	1984–88 R&D to sales ratio times current sales (max ratio of .16); .03 for startups	same	Subtract 100% of credit	same

which was a feature of the credit until 1990. The fact that increasing R&D spending in the current year raises the base in each of the three subsequent years means that for a firm that is always paying taxes, the effective tax credit would be zero except for the presence of discounting. A second feature that weakens the credit is the ceiling on incremental R&D, which is equal to the current year spending. Coupled with the effect of a large increase on the base in future years, this feature of the code produces large *negative* credit rates for rapidly growing firms.

The consequences of the third feature of R&D tax policy (foreign source income allocation rules) for the R&D performance of U.S. multinationals have been well discussed by Hines (1992) and will be covered only briefly here. Basically, the problem is one of allocation of fixed costs across income sources. U.S. tax policy is to tax firms on worldwide income, but to allow credits against that tax for taxes paid to foreign governments (Dept. of Treasury, 1983; Hines, 1992). These credits are limited by the U.S. tax, which would be due on the foreign source income. Thus, the allocation of income, and therefore costs, across jurisdictions matters to firms with excess foreign tax credits. If they already have foreign tax credits they cannot use, allocating more R&D to foreign source income does not reduce their tax liability[11] and will only increase their taxable U.S. income. This is somewhat mitigated by the fact that they are allowed to carry back and carry forward these excess credits.

In 1977, Treasury regulation section 1.861–8 specified the rules by which R&D expenditure should be allocated between foreign and domestic source income: these rules specify that all government mandated R&D (R&D for safety purposes, etc.) plus 30 percent of the remainder can be exclusively allocated to U.S. sales. The 70 percent remaining must be apportioned between domestic and foreign sales using either sales or income as the method of apportionment. The allocations must be done on the basis of product lines (two-digit level). Because of concern on the part of the president and Congress that this method of allocation disadvantages U.S. corporations competing internationally, regulation 1.861–8 was suspended by Section 223(b) of the Economic Recovery Tax Act of 1981; ERTA allowed all R&D expenditure to be allocated against income earned within the United States. The allocation rules have been reviewed and revised continuously since then; a summary of the changes is shown in the last column of Table 1.

Hines (1992) discusses the implication of these allocation rules for the

[11] This is because most foreign governments do not allow the expensing of R&D performed in the United States, and, therefore, the R&D allocated to foreign source income does not reduce the foreign tax liability (Hines, 1992; U.S. Dept. of Treasury, 1983).

incentives that multinational firms face to undertake R&D directed at domestic and foreign markets. As a general matter, he finds that the allocation rules tend to make R&D directed toward increasing domestic sales a relatively more expensive input than other ordinary inputs, but that R&D directed toward increasing foreign sales (but conducted in the United States) is substantially less expensive for firms with excess foreign tax credits. This latter fact is due to the relatively light royalty rates that foreign governments impose on royalties (which are the income that results from use of the R&D) paid to the United States. He studies 116 multinational corporations between 1987 and 1989, and finds that only 21 are in a deficit foreign tax credit situation. The average tax price for R&D directed toward domestic sales is 5 percent higher than that for other (noncapital) inputs, and the average tax price for R&D directed toward foreign sales is 15 percent lower, for an overall wedge of 20 percent.

Because of a lack of information on foreign and domestic income and sales, I will not be able to incorporate the features of the tax law that pertain to multinationals in the tax prices that I compute for R&D in the work reported here. Because the firms affected are probably about 10 percent of my sample, I expect that this will not make an enormous difference to the regression estimates, although it will definitely increase the error in the computed tax prices. However, because the tax situation of a multinational in several lines of business and in several countries facing different tax rates is so complex, these errors are unlikely to be systematically correlated with the tax prices I compute, which are based on worldwide R&D spending and taxable income. Under the assumption that this is the case, the estimates here will be valid, although it would be interesting in future work to combine my approach with Hines in order to obtain more precise estimates.

III. FRAMEWORK FOR ANALYSIS

In this section of the paper, I present the simple investment model that will be used to estimate the tax price responsiveness of R&D spending. Assume that a profit-maximizing firm earns revenues every period from its stock of R&D capital, which is the depreciated sum of past R&D investments. The treatment here is parallel to the usual treatment of physical capital; all other input factors are omitted in order to simplify the analysis, because the essential ideas can be seen without the added complication. With no adjustment costs, the firm's problem is

$$\underset{\{R_t\}}{\mathrm{Max}} \sum_{t=0}^{\infty} (1 + r)^{-t}[(1 - \tau)\, S(G_t) - \theta_t\, R_t] \qquad r > 0 \tag{1}$$

subject to

$$G_t = (1 - \delta)G_{t-1} + R_t, \tag{2}$$

where $S(.)$ is the sales (revenue) function, and θ_t is the tax price of R&D (if R&D is expensed as incurred, for example, θ_t will be $1 - \tau$ where τ is the corporate tax rate). With $S' > 0$ and $S'' < 0$, it is easy to show that the profit- and (value-)maximizing choice of $\{R_t\}$ is given by the Euler equation:

$$(1 - \tau)S'(t) = \theta_t - \frac{(1 - \delta)}{(1 + r)}\theta_{t+1}. \tag{3}$$

Therefore (if one assumes θ_t is equal to $(1 - \tau)$ for the moment), the firm invests so that its marginal revenue product (MRP) each period is equal to the depreciation on the capital stock plus the interest rate discounted to the present $[(\delta + r)/(1 + r)]$.[12] Clearly, a tax subsidy of the form $1 - \theta_t$ will reduce the required MRP and increase the level of R&D spending if $S'' < 0$. This type of subsidy is equivalent to shifting the required rate of return curve in Figure 1 outward by θ_t. Once again, if we knew R_S and the slope of the MRP curve, we could easily calculate the optimal θ_t.[13]

However, there are of course many reasons to think that this analysis is oversimplified: in order of tractability, three important considerations are (1) adjustment costs in R&D; (2) the fact that the required rate of return curve that firms face may be neither smoothly upward sloping nor roughly equal across firms because of liquidity constraints and the complexity of the corporate tax system; and, finally, (3) general equilibrium effects. The first two are considered here.

Many researchers (Bernstein and Nadiri, 1986; Hall, Griliches, and Hausman, 1986; Hall and Hayashi, 1988; Himmelberg and Petersen, 1990) have documented the apparently high adjustment costs that a firm investing in R&D faces. The principal evidence for this is the low variance of R&D expenditures within a firm relative to ordinary investment spending, or low responsiveness of R&D demand to changes in prices.

[12] Note that the result for this simple case with constant tax rates does indeed show that the corporate tax rate is irrelevant for R&D spending, even though the returns to R&D are spread over the future. This does *not* mean that R&D is not subsidized relative to investment, only that the subsidy affects investment rather than R&D.

[13] The model presented here is a simplification which is not valid when θ_t depends on future R&D spending (as it will in the case of the tax credit in place from 1981 to 1989). The correct model has a function of R_t, R_{t+1}, . . . in place of $\theta_t R_t$ as the cost of R&D. The appendix presents this more complex model and shows that equations (3) or (5), which will be used for estimation, remain unchanged when the correct model is used to derive them.

The phenomenon is frequently confirmed by those in industry; the fact that R&D budgets are at least 50 percent composed of the salaries of professional scientists and engineers (and that much of the "knowledge" capital of the firm is embodied in these workers) and the long-term nature of many projects would lead to this conclusion. If adjustment costs for R&D investment are indeed high, this fact has important consequences for the conduct of tax policy, particularly in an environment where uncertainty about the future plays an important role. For example, frequent tinkering with the tax system can be expected to diminish greatly the incentive effects of a tax subsidy to R&D, because firms facing both uncertainty about future tax policy and fluctuating tax prices will be reluctant to invest in the presence of high adjustment costs.

To make this concrete, I complicate the previous model by adding external costs of adjustment to R&D investment that are proportional to the intensity of such investment, and are minimized when R&D is exactly replacement investment; the firm's problem is now

$$\underset{\{R_t\}}{\text{Max}} \sum_{t=0}^{\infty} (1 + r)^{-t}\left\{(1 - \tau)[S(G_t) - \Phi(R_t,G_t)] - \theta_t R_t\right\}. \tag{4}$$

The solution to this problem is the same Euler equation as before, but with a set of terms that describe the difference in adjustment costs between this period and the next:

$$\begin{aligned}&(1 - \tau)\left\{S'(t) - \Phi_G(t)\right\}\\ &= \left\{\theta_t + (1 - \tau)\Phi_R(t)\right\} - \frac{(1 - \delta)}{(1 + r)}\left\{\theta_{t+1} + (1 - \tau)\Phi_R(t + 1)\right\}.\end{aligned} \tag{5}$$

The after-tax marginal revenue product of R&D in period t (which now includes the marginal reduction in adjustment costs as a result of increased capital) has to cover not only the interest and depreciation on the R&D capital, but also the increase in after-tax adjustment costs caused by having made the investment this period rather than next.

A few computations will illustrate why firm behavior is sensitive to the exact form of the subsidy. Assume $r = .10$, $\delta = 0.15$, and $\tau = 0.34$. With no adjustment costs and no additional tax subsidy ($\theta_t = 1 - \tau$), they imply a required pretax marginal revenue product for R&D of about 23 percent. Now assume that marginal adjustment costs $\Phi_R = 1.5$, which is consistent with the results reported later in this paper. The required pretax marginal revenue product for R&D capital is now 58 percent. Unless many such high-return projects can be found, the optimal strategy may be to keep adjustment costs low by deferring investment until a later period.

Although it is not possible to do a complete analysis using the Euler equation without knowing the future path of R&D investment for the firm, it is fairly easy to convince oneself that any wedge in adjustment costs between periods caused by differing investment rates induced by a short-term or temporary tax subsidy to R&D would swamp the direct effect of the subsidy on the required rate of return in this model and with adjustment costs of this magnitude. In other words, the typical manufacturing firm has an enormous incentive to smooth the acquisition of R&D capital, and this greatly inhibits the effectiveness of *temporary* tax instruments.

The preceding analysis is not intended to be conclusive, because there still exists considerable doubt in the literature as to the form and magnitude of the adjustment cost function in this case. However, it does highlight the importance of exploring the question of the responsiveness of R&D to changes in price, particularly in light of the conflicting results in the literature.[14] At the same time, I would suggest that the qualitative implications of the previous estimates of R&D factor demand will remain true even as we improve the modeling of adjustment costs: short-term tax instruments are unlikely to be the cost-effective weapon for increasing R&D investment.

Figure 1 shows a smooth, upward-sloping supply curve for R&D investment funds, representing the changing rate of return required by investors as a firm invests more and more dollars in R&D. This is unlikely to be an accurate description of a world with asymmetric information and taxes. Many economists (Auerbach, 1984; Fazzari, Hubbard, and Petersen, 1988; Poterba and Summers, 1985) have made the point that this supply curve may have kinks at the individual firm level. In a recent series of papers (Hall, 1991, 1992), I have applied this idea to R&D investment and found evidence both that R&D investment is simultaneous with the choice of financial structure (and that highly levered structures are not favored by R&D firms) and that liquidity itself, as measured by cash flow, is as important a determinant of R&D investment as of ordinary investment.

Using a more complex version of the model sketched earlier, which contains three sources of finance (debt, new equity, and retained earnings), corporate and individual taxes, a lemons premium for new equity,

[14] As discussed earlier, Hines (1992) finds a price elasticity of about unity for R&D spending, but previous estimates (e.g., Bernstein and Nadiri 1988 or Mansfield 1986) have found numbers of the order of magnitude of 0.2 to 0.5 for R&D capital. Comparing the two sets of numbers is difficult owing to the heterogeneity of the R&D spending patterns for the firms in the data samples used.

and a cost of debt that is increasing in the capital-debt ratio, one can derive a supply curve for investment funds to an individual firm (Fazzari, Hubbard, and Petersen, 1988; Hall, 1992; Poterba and Summers, 1985). This curve has three regions: one where the cost of funds to the firm is low because the marginal source of finance is retained earnings (and even lower if there is a tax-induced wedge between dividends and capital gains), a region where the cost of funds rise, possibly steeply, as the firm borrows to finance investment, and finally a region where the marginal source of finance is new equity, which is issued at a premium because of the possibility of lemons in this market.

Casual observation and the empirical evidence both suggest that R&D firms are likely to find the central portion of this figure rather inhospitable when thinking about R&D investment, and that they will either be pursuing a policy of "living within their means" or, if their investment opportunities look profitable enough, going to the equity or venture capital markets to finance them. This means that tax credits will translate one-for-one into R&D expenditure if the firm has income tax liabilities but is liquidity constrained. On the other hand, because R&D is expensed for tax purposes, young high-technology firms that are investing heavily in R&D may not have tax liabilities against which to use the credit, which will limit its effect.

The main implication of liquidity-constrained investment for optimal R&D tax policy is that the required rate of return or supply curve of funds for an individual firm may not look at all like the one a social planner would use in choosing the optimal level of R&D investment. For example, suppose that a (fully informed) society's required net rate of return for investment is just the discount rate, which implies a flat supply curve of funds. Then the optimal level of R&D investment is likely to be quite large relative to the competitive level, and from this we can calculate an appropriate subsidy. But some individual firms may face steeply rising rather than flat cost of funds schedules, and the R&D elicited by the subsidy will be substantially less than the amount expected by the social planner when he set the subsidy rate. The conclusion is that it might be important to investigate the heterogeneity of R&D response to changes in tax price across firms in different financing regimes in considering the effects of such a subsidy.

IV. THE DATA SAMPLE AND ESTIMATED CREDIT RATES

The analysis in this paper is performed using a large sample of U.S. manufacturing firms drawn from the 1980–1991 Compustat (Standard and Poor, 1992) files. This sample includes essentially all publicly traded manufacturing firms, accounting for about 85 percent of R&D performed and paid for by industry. The panel that is analyzed here is restricted to R&D-performing firms that have at least four years of continuous data between 1977 and 1991. There are about 1,000 firms per year (the exact number is shown in Table 2), with an incomplete sample in 1991 caused by differences in fiscal years.[15] The sample is much the same as the one that I have analyzed in several previous papers (Hall, 1990a, 1991, 1992), but updated through 1991.

There are two major drawbacks to using this data source for the project at hand: lack of information on the fraction of total R&D spending that is qualified under the R&E tax credit, and lack of detailed information on the tax status of the firm. To solve the former problem, I have relied on estimates obtained from confidential tax data by Altshuler (1988); her estimates were consistent with those of Eisner, Albert, and Sullivan (1984), obtained from the McGraw-Hill R&D survey and NSF. I assume that every additional dollar spend on R&D has the same composition of qualified and unqualified expenditures as the average. Obviously this is an oversimplification: presumably part of the intent of the law was to shift spending toward "technological" directions, and it would be interesting to know to what extent this goal was achieved. Without access to confidential data, however, it is not possible to investigate this question. There is a bit of tantalizing information on this question in the GAO Report (1989): by comparing 219 corporations for which they had both confidential tax data and COMPUSTAT R&D spending data, they were able to conclude that although qualified spending grew only 1.04 times more rapidly than total spending over the 1980–1985 period, there was substantial variation (for these firms) within the period, with qualified spending growing 1.46 times as fast in the 1980–1981 period, but only 0.72 times as fast in 1983–1984.[16]

With respect to tax status, COMPUSTAT contains information on taxable income and loss carryforwards, but no detail on unused business credits; in addition, Altshuler and Auerbach (1990) and others have found the tax data on Compustat not always accurate or consistent with IRS records. Because there is very little I can do about this problem without using confidential tax data, it must be kept in mind that my estimated tax prices for R&D are likely to be mismeasured for some firms because of this.

[15] Because of the way Compustat dates firm-years, data for firms that close late in fiscal 91, i.e., in the first few months of 1992, are not yet available).

[16] U.S. Government, Report GAO/GGD-89-114, pp. 77–78.

TABLE 2.
U.S. Manufacturing Firms 1980–1991.

Year	Number of Firms	R&D Deflator (1982 Dollars)	Total R&D Spending (B 1982 Dollars)	Share of NSF R&D (Percent)	R&D to Sales (Percent)	Average Growth Rate of R&D (Percent)
1980	1006	0.890	30.30	87.2	1.99	9.13
1981	994	0.957	32.13	85.5	2.05	10.29
1982	991	1.000	33.96	83.5	2.34	10.62
1983	1015	1.036	36.17	82.8	2.55	8.55
1984	1012	1.085	40.29	82.8	2.88	12.28
1985	985	1.134	40.92	80.0	3.03	6.33
1986	978	1.150	43.01	80.9	3.40	5.97
1987	974	1.156	45.33	81.8	3.36	7.94
1988	944	1.196	47.83	84.3	3.27	6.36
1989	893	1.241	50.03	88.3	3.37	4.21
1990	859	1.295	51.14	86.8	3.34	2.93
1991	735	1.343	51.04	89.2	3.62	0.96

The R&D deflator is a weighted average of labor costs and the implicit price deflator in the nonfinancial corporate sector and is described in Hall (1990a).

The NSF R&D numbers are the total R&D expenditure by industry, from Science Indicators 1987, updated by growth rates in the *New York Times* (1992).

The R&D to Sales average is a sales-weighted average, which is the same as the ratio of total R&D during the period to total sales by R&D performing firms.

However, all studies in this area face a more serious measurement problem when using tax prices computed *ex post* with a knowledge of the complete history of the firm over the period. What matters for the optimizing problem sketched in the previous section is the tax price that is expected to prevail when the investment decisions are undertaken. Because of the history of the R&E tax credit legislation, and general uncertainty about taxable income, there is no reason to think that the price expected by the firm is the one that is computed using information from later years, such as future tax status. To solve this problem, I make the usual rational expectations assumption, and compute the expected price faced by the firm as the regression of the realized price on variables known to the firm at time $t-1$. The instruments used include the past tax status of the firm, and its sales and R&D growth rates. This list of variables should not only be good predictors of the *expected* tax price, but they should also help with ordinary measurement error.

Table 2 shows some of the characteristics of my sample, and highlights the trends in industrial R&D spending during the 1980s. Although the 1991 numbers need to be interpreted with caution because of the incompleteness of the sample for this year, it is possible to draw some simple conclusions from these numbers. The National Science Board has recently issued a report documenting stagnation or decline in industrial R&D during the latter half of this period (National Science Board, 1992). While Table 2 lends some support of their view, it also alters the interpretation slightly. Table 2 shows that real R&D spending, measured either in total, as a weighted R&D to sales ratio, or at the firm level, was rising at about 10 percent per year during the 1980 through 1984 period. From 1985 through 1990, although total spending continued to rise at a much slower rate, and weighted R&D to sales ratios increased somewhat, average firm R&D growth rates were still over 6 percent per year, declining only in 1989 and 1990. The explanation for this inconsistency appears to lie in the fact that the manufacturing sector was shrinking during the period, both in number of firms and in output, so that although R&D stagnated during this period, it did not do so as much as sales, and many smaller firms were increasing their R&D spending substantially, especially before 1990.

By itself and ignoring all other macroeconomic effects, Table 2 seems to suggest success for the first few years of the R&E tax credit, followed by diminishing returns and then complete failure of the improved credit of 1990. As we will see, in addition to ignoring such factors as recession during the latter half of the period, this interpretation fails to take account of the other features of the corporate tax system that were changing at the same time, which had the effect of increasing the *relative* tax price of R&D from 1986 onward. The regression results reported later show that the cross-sectional responsiveness of R&D to differences in tax prices was unabated throughout the period, although there was certainly an unexplained decline in R&D spending for these firms in 1990 and 1991.

Before turning to the regression results, I present some basic facts on the computation of the R&E tax credit in Table 3. As alluded to earlier, R&D tax policy for domestic firms consists of two parts: the expensing of R&D reduces the cost by the corporate tax rate if a firm has taxable income (discounted if there are loss carryforwards) and the subsidy from the credit (multiplied by the share of R&D expenditures which qualify for the credit). These two pieces are shown in the equation for the tax price of R&D:

$$\theta_t = p_t^R(1 - T_t(1 + r)^{-J_t}\tau - \eta_t \mathrm{ERC}_t). \tag{6}$$

p_t^R is the "price" of R&D investment absent taxes, T_t is a dummy that indicates whether a firm has taxable income in the current year (not necessarily whether it actually pays taxes), J_t is the number of years

TABLE 3.
The R&E Tax Credit in Practice.

Year	Average Effective Credit (Percent)	Wtd. Av. Effective Credit (Percent)	Average Tax Price of R&D	Deflated Tax Price of R&D	*Revenue Cost (Millions Dollars)* This Paper	GAO Estimate	Actual
1980	0.0	0.0	1.000	1.000	0.0	0.0	0.0
1981	3.04	3.45	0.963	0.940	738.	800.	NA
1982	5.05	3.80	0.941	0.905	1025.	1200.	859.2
1983	3.64	5.02	0.958	0.917	1400.	1500.	1277.5
1984	4.60	4.98	0.947	0.909	1953.	1800.	1589.1
1985	5.01	5.38	0.942	0.912	1793.	1700.	1628.0
1986	3.11	3.60	0.970	0.927	1208.	—	1292.0
1987	2.66	3.61	0.975	0.908	1183.	—	1053.3
1988	3.50	4.25	0.967	0.895	1429.	—	1276.9
1989	2.19	3.39	0.980	0.903	1272.	—	NA
1990	7.69	10.52	0.928	0.857	857.	—	NA
1991	7.49	11.17	0.930	0.859	922.	—	NA

See text for calculations of the effective R&E tax credit and the relative tax price of R&D. The column labelled "Wtd." shows the average credit weighted by R&D spending in each firm. The deflated tax price is the tax price multiplied by R&D deflator relative to the GNP deflator (1980 = 1).

The last three columns show the revenue cost of the credit, first estimated from Compustat and inflated by the coverage ratio for the NSF survey shown in Table 2, then from the GAO Report (1989), which is based on *Statistics on Income* data on about 800 large corporations, and finally the actual reported totals from the *Statistics on Income* for the entire corporate sector. NA means the number is not available.

before any loss carryforwards will be exhausted (usually equal to zero), τ_t is the corporate tax rate, η_t is the share of qualified R&D expenditure, and ERC_t is the effective rate of R&E tax credit. This quantity is computed using the following general formula:[17]

$$\begin{aligned} \mathrm{ERC}_t = \rho_t\Big(& (1+r)^{-S} Z_t - (1/3)\Big\{(1+r)^{-(1+J_{t+1})}(Z_{t+1} > 0.5) \\ & + (1+r)^{-(2+J_{t+2})}(Z_{t+2} > 0.5) + (1+r)^{-(3+J_{t+3})}(Z_{t+3} > 0.5)\Big\}\Big) \qquad (7) \\ & \qquad\qquad \text{for } t = 81 \text{ to } 89 \\ \mathrm{ERC}_t &= \mathrm{ERC}_t\,(1 - 0.5\tau_t) \qquad \text{for } t = 89 \\ \mathrm{ERC}_t &= \rho_t (1+r)^{-s}(1-\tau_t)\, Z_t \qquad \text{for } t = 90{,}91, \end{aligned}$$

[17] The computation shown here is essentially that in the GAO report (1989) suitably modified to take account of changes in the tax law since 1985. The second term in equation (7) is multiplied by one-half rather than one-third in 1981, because of the special startup rules during the first two years of the credit.

where ρ_t is the statutory credit rate and Z_t is zero, one half, or one, depending on whether R&D spending during the year is below the base level, more than twice the base level, or between one and two times the base level. If the firm can carry back the credit, s is the (negative) number of years it will do so, with a maximum of three. If it must carry forward the credit, s is positive. The terms in brackets represent the effects on the future R&D base of increasing expenditures at the margin this year.

The first two columns of Table 3 give the effective marginal tax credit faced by the average firm in this sample, unweighted and weighted by the actual R&D spending of the firms. The effective credit is somewhat higher than that reported by Altshuler (1988) for 1981 through 1984, because my sample includes only R&D-performing firms, and is consistent with the GAO study for 1981 through 1983. It is clear from the table that firms with more R&D also face a slightly higher credit rate on average (because presumably they are more likely to be above the base expenditure level). Column 3 of Table 3 shows the relative tax price of R&D (the tax price divided by one minus the corporate tax rate actually faced by the firm on earnings); this ratio is unity when there was no R&D credit. Column 4 shows the average of the relative price of R&D actually used in the regressions later; this is the tax price multiplied by the ratio of the R&D deflator to the GNP deflator. It falls more than the tax price during the 1980s because the R&D deflator did not rise as fast as the GNP deflator, because of the large share of labor costs in the former.

From the perspective of the government, there is a cost associated with tax subsidies, in spite of the economic theorist's confidence that nondistortionary lump sum taxation will be used to finance them. In the real world, distributional considerations and the complexities of the existing tax system may preclude that simple solution. The framers for the R&E tax credit legislation clearly were attempting to minimize its revenue cost by focusing on the incentives to increase R&D at the margin: in the simple world of Figure 1, rather than giving $(1 - \theta)R_S$ to the firm, they attempted to set the subsidy at $(1 - \theta)(R_S - R_C)$ by allowing firms to use a credit only on qualified research expenditures above a base determined by the firm's prior history of research spending. It is this feature of the credit that, although admirable in intent, has led to the weak incentive effects observed and controversy over its continuance.

The last three columns of Table 3 give some idea of the revenue cost associated with the R&E tax credit. This was computed by calculating the tax credit that actually would have been claimed in any given year by each of these firms, assuming that I have identified those with taxable income correctly, adding up the numbers, and then inflating them to population totals using the share of NSF R&D expenditures shown in Table 2. For comparison, the GAO (1989) estimates are shown for the period for which they are available. Although they are not identical, it is reassuring that the numbers computed here are not wildly different from estimates computed using actual tax returns. I also show the actual numbers reported by the IRS for the whole corporate sector in *Statistics on Income;* these are generally somewhat lower than both my numbers and the GAO numbers, which may reflect the results of auditing returns, or errors induced by fiscal year timing.

To give an idea of the dispersion in the rates faced by different firms as well as the sources of this heterogeneity, Table 4 shows the fraction of firms whose effective credit rate is *negative,* the share of R&D in firms with negative marginal credit rates, the fraction of firms with R&D below the base amount, and the fraction above twice the base. The share of firms facing a negative credit rate drops to zero and the number of firms

TABLE 4.
The Heterogeneity of the R&E Tax Credit.

Year	Percent of Firms with Negative Effective Credit	Share of R&D in Firms with Negative Credit	Percent of Firms below Base R&D	Percent of Firms above 2*Base	Percent of Firms with Taxable Income
1977	—	—	20.5	9.9	93.6
1978	—	—	16.9	9.8	94.1
1979	—	—	16.2	10.9	93.1
1980	—	—	13.1	13.2	89.8
1981	17.9	6.4	19.3	5.3	90.1
1982	19.2	13.5	20.2	9.9	80.7
1983	24.2	8.9	23.9	12.7	82.5
1984	21.7	13.3	20.9	13.6	83.7
1985	21.0	8.4	21.5	12.0	80.5
1986	24.4	10.3	26.5	9.4	81.2
1987	26.7	11.2	29.8	10.0	85.1
1988	22.4	10.2	28.3	9.2	85.8
1989	30.6	11.3	25.4	8.5	83.8
1990	0.0	0.0	38.2	8.3	83.5
1991	0.0	0.0	40.1	7.6	78.9

Firms with a negative effective credit are those whose marginal R&E tax credit rate as computed by equation (7) is less than zero. The second column shows the total share of R&D spending which is in such firms.

The share of firms below and above base R&D for the years 1977 through 1980 is a hypothetical computation which assumes that the base is the average of the last three years of spending.

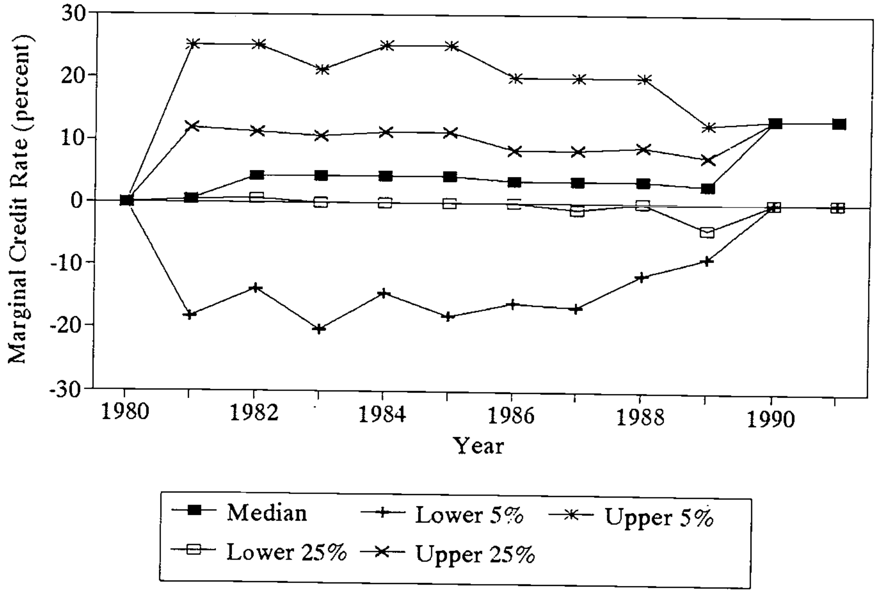

FIGURE 2. ***Effective R&D Credit Rate: U.S. Manufacturing Firms 1981–1991.***

below the base level increases when the new formula for the base is introduced in 1990. The dispersion in effective credit rates is also shown in Figure 2, where the median, interquartile range, and 5 and 95 percent bounds of the effective credit rate are plotted against time. For the early years, the dispersion is extremely large; it falls slightly in 1986 when the corporate tax rate and statutory credit rate were reduced, and again in 1989 when the offset to section 174 deductions is introduced. After the Budget Act of 1989, there are basically two rates: 13.2 percent (= (1 − .34)*.20) for firms above the base who have taxable income, and zero for firms which are below the base or do not have taxable income.[18]

The interaction between the R&E tax credit or accelerated depreciation and the tax status of firms has not gone unnoticed by previous researchers in this area, but there is no consensus on the importance of the effect. Eisner, Albert, and Sullivan (1984) seem to have been the first to make the point that the effective rate of tax credit can be substantially less than

[18] In the last few years, I am unable to look ahead to when the firm will have taxable income against which to use the credit, so I am forced to assume that all firms become taxable in 1992 in order to perform the computations. This overestimates the average credit slightly.

the statutory rate, and possibly even negative for firms *currently* in an excess tax credit position but not expecting to be in future years.[19] They find that 15 percent of their sample cannot use the credit in 1981, and 35 percent in 1982, which suggests a considerable weakening of the desired effect. On the other hand, the GAO (1989) study claims that the actual average effective tax credit rises only from 5.2 percent to 5.9 percent in 1982 (the year with the *largest* effect) if one makes the counterfactual assumption that companies receive refunds for credit amounts that they cannot use immediately. The explanation for these results appears to lie in the intertemporal behavior of tax status, as reported by Altshuler (1988): she finds that during the early 1980s, only 3 percent of firms on average transit from nontaxable state to a taxable state. It is these firms that experience the most negative incentives from the tax credit, but they are so few in number that it is not surprising that they have minimal effect on the computation of average behavior. The majority of tax-exhausted firms one year remain tax-exhausted in the future, and these firms experience neither an incentive nor a disincentive effect from the tax credit.

V. ESTIMATION RESULTS

Estimating investment demand equations at the firm level is difficult and prone to fragile results; there is also a large literature on the subject that is not discussed extensively here because of space considerations. In earlier work (Hall, 1991, 1992), I have investigated the modeling and specification of the R&D investment equation. The estimates reported here rely heavily on insights and specification testing that was performed in the course of that work. The approach used is to assume a Cobb-Douglas form for the production function (with a coefficient γ for R&D capital G_t) and an adjustment cost function of the form

$$\Phi(R_t, G_t) = \frac{\phi}{2}\left\{\frac{R_t}{G_t}\right\} R_t. \tag{8}$$

In the appendix, these assumptions are combined with equation (5) to obtain a Euler equation for investment, which can be written as follows:

[19] This seemingly bizarre result occurs because qualified research spending done in the current year raises the base above which the increment is calculated in future years, thus lowering the amount that is eligible for the credit in the future year. The firm gets no credit in the current year and can carry the credit forward for only three years, while it may find that future credits have been reduced because of the increased spending.

$$\left(\frac{R_t + 1}{G_t + 1}\right) = \frac{(1 + r)}{(1 - \delta)}\left\{\left(\frac{R_t}{G_t}\right) - \frac{1}{2}\left(\frac{R_t}{G_t}\right)^2 + \phi^{-1}\left\{\frac{\theta_t}{(1 - \tau_t)} - \gamma\frac{S_t}{G_t}\right\}\right\} \qquad (9)$$
$$- \phi^{-1}\frac{\theta_t + 1}{(1 - \tau_{t+1})}$$

This equation specifies that the current rate of investment depends on the lagged rate through the adjustment cost terms, and is related negatively to the lagged marginal product of capital (because the firm will have invested last period if the marginal product was high) and negatively to the discounted increase in the price of R&D.

Estimating an equation like equation (9) requires the use of instrumental variables for several reasons: all of the right-hand-side variables (even the actual tax price faced) are under control of the firm at the same time

TABLE 5a.
The Response of R&D to the Tax Price, U.S. Manufacturing 1980–1991 GMM Estimates.

Independent Variable	1980–1991	1980–1985	1986–1991	First Diff. 1980–1991
Sales-R&D Capital Ratio Lagged	.0001(.0001)	.0001(.0001)	.0002(.0001)	.0009(.0014)
R&D Investment Rate Lagged	.988 (.031)	.957 (.047)	.973 (.029)	.656 (.181)
Squared R&D Investment Rate Lagged	−.221 (.034)	−.137 (.052)	−.248 (.033)	−.187 (.149)
Tax Price	−.362 (.042)	−.320 (.063)	−.356 (.053)	−1.21 (.29)
Tax Price$_{-1}$	.250 (.059)	.305 (.098)	.147 (.054)	.374 (.095)
$\chi^2(2)$ for price effects	74.1	38.0	46.2	17.2
Year Dummies	incl.	incl.	incl.	incl.
Std. Err.	.096	.102	.087	.195
Std. Dev. of Dep. Var.	.183	.187	.180	.079
No. of Obs.	9167	4807	4360	9167

The method of estimation is Generalized Method of Moments (GMM) (robust to heteroskedasticity) where the instruments include the right-hand-side variables lagged twice and three times, the growth rates of R&D, sales, and taxes lagged twice, and tax status (whether taxable income and whether actually paying taxes) lagged once and twice.

Standard error estimates are robust to the presence of heteroskedasticity and first order serial correlation.

as it is planning its future R&D expenditure path, so we expect that there will be a relationship between the disturbance to this equation and the right-hand-side variables. In addition, many of the variables are likely to be measured with error. In particular, as discussed earlier, the tax price variable that I have computed is extremely unlikely to be the actual tax price the firm faced, and it is certainly not the price that the firm expected at the time the investment decisions were being made; in fact, as the history of the R&E tax credit legislation shows, firms are unlikely to have been able to forecast the exact tax treatment of R&D more than six months or so in advance. For all these reasons, the estimates of this equation reported in Tables 5(a) and 5(b) use values of the right-hand-side variables lagged twice and three times as well as lagged tax status and lagged growth rates in R&D and sales as instruments.

TABLE 5b.

The Response of R&D to the Tax Price, U.S. Manufacturing 1980–1991, December Fiscal Year Close Only GMM estimates.

Independent Variable	1980–1991	1980–1985	1986–1991	First Diff. 1980–1991
Sales-R&D Capital Ratio Lagged	−.0002(.0001)	−.0001(.0001)	.0001(.0001)	.0008(.0019)
R&D Investment Rate Lagged	.936 (.037)	.878 (.054)	.968 (.040)	.552 (.288)
Squared R&D Investment Rate Lagged	−.165 (.045)	−.032 (.057)	−.224 (.045)	−.103 (.235)
Tax Price	−.368 (.048)	−.315 (.057)	−.374 (.063)	−.585 (.270)
Tax Price$_{-1}$	.195 (.052)	.222 (.074)	.155 (.060)	.179 (.092)
$\chi^2(2)$ for price effects	39.1	32.6	36.1	4.69
Year Dummies	incl.	incl.	incl.	incl.
Std. Err.	.081	.080	.078	.112
Std. Dev. of Dep. Var.	.162	.159	.166	.083
No. of Obs.	5077	2650	2427	5077

The method of estimation is Generalized Method of Moments (GMM) where the instruments are the right-hand-side variables lagged twice and three times, the growth rates of R&D, sales, and taxes lagged twice, and tax status (whether taxable income and whether actually paying taxes) lagged once and twice.

Standard error estimates are robust to the presence of heteroskedasticity and first order serial correlation.

The model in equation (9) is a rather rigid structural model with which to estimate the behavior of over 1,000 manufacturing firms in many industries: besides the fact that it does not allow for the heterogeneity in such a sample, there is no reason to think that either the functional form or the assumption that R&D can be analyzed independently of other inputs, are close to correct. Thus, it is reassuring to see in Table 5(a) that the signs and magnitudes of the estimated coefficients are not wildly at variance with our priors. The signs and orders of magnitude of all significant coefficients (those on the lagged R&D investment rate and its square, and on the current and lagged tax prices) are correct. It is discouraging, however, that the output-capital does not play a role: the implied γ is about .0004–.0008, which is far below the value of .05 or .10 that might have been expected given price-taking firms with R&D capital shares of roughly that order of magnitude. This is undoubtedly due in part to the unrealistic production model presented here, which is oversimplified to the extent of ignoring all other inputs into the production process. As is usual in R&D investment regressions at the firm level, by far the most significant predictor of R&D investment is past R&D investment: this is just another aspect of the adjustment cost story, but it may also indicate substantial technology-related firm heterogeneity. For example, in a steady-state world with differing depreciation rates for R&D capital across industries, we would expect the lagged R&D investment rate to be a good predictor of the current rate. Lagged R&D investment may also be a fairly good indicator of the marginal revenue product of R&D capital, which would account for the disappointingly low coefficient on the output-capital ratio.

The main result of the estimation reported in Table 5(a) is that the tax price response of R&D is significant and not due to simultaneity of taxable income and R&D. However, when the sample is broken into two periods corresponding to before and after the 1986 Tax Reform Act, the price response is stronger in the latter period than in the former (a joint significance test for the two coefficients that is based on the heteroskedastic-consistent standard errors is shown in the table). It is intriguing that the earlier period shows a somewhat weaker response, which might be expected as firms adjust their R&D spending plans to the new law, and become reassured that it is quasi-permanent.

The last column of Table 5(a) presents estimates based on first differences of the variables; these estimates control for unexplained differences across firms that may be related to the right-hand-side variables and, therefore, bias the coefficient estimates. Although somewhat less precise, these estimates confirm those in the first three columns and in fact show a substantially larger effect of the tax price, controlling for unexplained differences across firms and industries.

TABLE 6.
R&D Response to the Tax Price: Logarithmic Specification, U.S. Manufacturing 1980–1991
9167 Observations
GMM Estimates.

Independent Variable	Estimates in Levels		Estimates in First Differences		
Log R_{-1}	1.003(.004)	.999(.004)	.431(.071)	.307(.051)	—
Log P	−2.48 (.16)	−1.90 (.14)	−1.95 (.47)	−.83 (.16)	−1.21(.14)
Log P_{-1}	1.39 (.19)	—	.40 (.16)	—	—
Log S_{-1}	−.031(.004)	−.011(.004)	.34 (.09)	.51 (.06)	.74(.05)
Std. Err.	.329	.311	.355	.297	.296
DW stat.	1.95	1.56	2.53	2.27	2.03

R, P, and *S* are R&D expenditures, the tax price, and sales respectively. All equations and instrument lists contain time dummies. The instruments are the same as for Table 5, in logarithmic form (levels and growth rates).

The method of estimation is Generalized Method of Moments and the standard error estimates are robust to heteroskedasticity and first order serial correlation.

One possible measurement problem with the preceding results arises because the fiscal year closings of firms are spread throughout the year rather than coincidental with the end of the calendar year. This could create difficulties with my measured tax prices because the tax law is generally on a calendar year basis. Therefore, Table 5(b) shows the same estimates as Table 5(a), with the sample constrained to those firms whose fiscal year ends in December. These estimates are similar to those in Table 5(a), so the timing of the tax changes does not seem to be a serious problem for estimation.

There are many reasons to think that the Euler equation approach to estimating investment behavior is not necessarily a good approximation to the behavior of large heterogeneous manufacturing firms.[20] Therefore, Table 6 presents a purely descriptive log-log regression of R&D on tax price to check the results obtained previously using a more robust specification. The results in this table strongly confirm the previous estimates, and in fact strengthen them: in all specifications of the model, the tax price elasticity of R&D is unity or slightly above. Because the original model included a lagged endogenous variable whose estimated coefficient was near unity, moving to first differences does not change

[20] For example, the possible failure of firms to maximize profits dynamically, variations in the form of the production function and adjustment cost function across firms and industries, aggregation over many lines of business within a firm, and failure of the expectational assumptions necessary to justify the equation.

the estimates or standard error of estimate that much, but it does have implications for the sales coefficient. When we look across firms at the level of R&D spending, the lagged R&D coefficient leaves little for any other variables to explain, particularly one like log sales, which is highly collinear with log R&D in the cross section. On the other hand, when we focus on growth rates, lagged sales growth does help to predict R&D growth, even in the presence of lagged R&D growth. Because tests of whether the firm effects are not correlated with the right-hand-side variables in this regression usually reject strongly (Hall, 1991, 1992), I am more inclined to rely on the estimates in the last three columns than in the first two.

From the estimates in Tables 5 and 6, it is possible to compute the predicted effect of changes in the tax credit on R&D investment, but it is important to distinguish between short- and long-term changes in so doing. The implied short-run price elasticity of R&D (based on the first-differenced specifications evaluated at the average R&D investment rate) is −0.84(.20) for column 4 of Table 5(a) and −1.5(0.3) for column 4 of Table 6. This means that a fully anticipated one-time reduction in the tax price of R&D of 5 percent (or an increase in the credit of 5 percent) would increase R&D spending after two years by approximately 13 percent using the estimates in Table 5(a) or 8 percent using the estimates in Table 6.

The long-run estimates based on these coefficients are larger, because of the multiplier implied by the lagged R&D coefficient in either version of the model. Unfortunately, this multiplier also makes the estimates quite imprecise: the long-run price elasticity in Table 5(a) at the mean R&D investment rate of 0.22 is −2.0(0.8), and for Table 6 it is −2.7(0.8). These estimates imply that a permanent R&E tax credit of 0.05 would be followed by permanent increases in R&D spending of anywhere from 10 to 15 percent *holding all else constant;* most of this increase would occur in the first three or four years of the credit. This estimate should be viewed with caution, because it may not be appropriate to extrapolate the relatively fragile linearized R&D investment demand equations to changes of this order of magnitude. Even though the marginal product of R&D capital has not entered the relationship significantly in Tables 5(a) and 5(b), we might still expect diminishing returns to play a role with changes on the order of 15 percent.

VI. DISCUSSION AND CONCLUSION

The GAO study (1989) estimated that the R&E tax credit stimulated between $1 billion and $2.5 billion dollars additional spending on research at a cost in foregone revenue of approximately $7 billion dollars during the 1981–1985 period. Baily and Lawrence (1992) obtained much higher estimates using aggregate data, averaging about $2.8 billion (1982 dollars) per year from 1982 to 1989. The present study shows that the earlier GAO estimates and other studies cited may have understated the benefits of the tax credit, and that the Baily and Lawrence estimates may be closer to the truth. I estimate that the additional spending stimulated in the short run was about $2 billion (1982 dollars) per year, while the foregone tax revenue was about $1 billion (1982 dollars) per year.[21] However, it needs to be kept firmly in mind that my tax data estimates are not likely to be as good as those constructed using IRS data, and that it might be worthwhile to update earlier studies that made use of these confidential data. Still, the numbers reported here do suggest that the credit is now having an impact, after a somewhat slow beginning.

If we accept the evidence that the R&E tax credit has increased the publicly reported R&D spending of U.S. manufacturing firms, there remains the question of whether this R&D spending truly reflects increased spending of the sort envisioned by Congress (research and experimentation in the laboratory or technological sense), or merely a relabeling of related expenses as research, and an increase in such expenses as new-product-related market research, etc. Answering this question is beyond the scope of either this study or the data now available. However, there is some evidence on the topic: in the early years of the credit, in particular, the IRS frequently (in more than half the cases) audited the credit claimed, with differing outcomes for the firms. A survey of IRS agents conducted by GAO provides evidence on this question (GAO, 1989). Although firms undoubtedly tried to claim some unqualified expenditures under the credit, the total amounts disallowed remain fairly small. In addition, there has always been an incentive to relabel investment expenses as R&D in the tax system, and this type of relabeling is already in the base level of R&D from which the incremental effect is calculated. For both these reasons, it seems likely that a large share of the reported increase in R&D in response to the tax credit is real, rather than spurious.

The main contribution of this paper is to confirm that the R&D spending of a firm does respond to financial incentives on the margin, al-

[21] These estimates are obtained by simulation at the individual firm level and then adding up the numbers, so that they reflect the heterogeneity inherent in the data. Previous studies have relied on estimates evaluated at the aggregate level, which may not give a completely accurate picture in the presence of significant nonlinearities. Because of the redesign of the credit in 1990 and 1991, for these years the R&D spending induced by the tax credit appears to be even higher, on the order of 5 billion per year. This number is almost too large to be credible (it is about 10 percent of R&D spending), and deserves further investigation as more data become available.

though the response is greatly dampened by the long-run nature of such investment. Together with the initial defects in the credit design, the high adjustment costs of R&D and learning by firms are probably the reason that the response appears to have been slightly larger in the latter half of the 1980s. In addition, two points about R&D tax policy and tax policy in general that have emerged here should be underlined: first, it may not be possible to achieve a long-term investment strategy with a short-term tax policy. Second, tax instruments cannot be viewed in isolation; it is important to look at the whole corporate tax system as it impinges on the activity in question when evaluating its effects. In the case of R&D, the interaction of the foreign tax credit, the R&E tax credit, and the AMT deserve further study, and can conceivably lead to quite perverse investment incentives. Of course, combining both these bits of wisdom into action may be an impossible task!

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APPENDIX: THE R&D INVESTMENT EQUATION UNDER UNCERTAINTY

Equation (9) in the body of the paper is used to estimate the demand for R&D investment given the tax price of R&D. This equation actually describes an equilibrium relationship between R&D performed in different periods as a function of changing tax prices, a relationship that holds conditionally on information available to the firm at the time it chooses its R&D policy. Thus, the appropriate method of estimation is instrumental variable (where the instruments are drawn from the information set of the firm at time t) rather than ordinary least squares. The problem of the firm is inherently subject to uncertainty about its own future demand and costs, and about future tax policy, but the model presented in the paper has abstracted from this uncertainty in order to simplify the presentation. This appendix describes the derivation of equation (9) from an expected dynamic profit maximization problem at the firm level.

The firm's problem is to choose an R&D policy to maximize the following expression:

$$E_t \sum_{s=0}^{\infty} (1 + r)^{-s} \Big\{ (1 - \tau)[S(G_{t+s}) - \Phi(R_{t+s}, G_{t+s})] - h(R_{t+s}, R_{t+s-1}, R_{t+s-2}, R_{t+s-3}) \Big\}$$

subject to the capital accumulation constraint given in equation (2) of the paper. The function $h(.)$ represents the total after-tax cost of R&D performed this year; this cost is a function of R&D spending during the last three years because of the effect of the base R&D level on the tax credit which will be earned this year. The information set at time t includes the current capital stock G_t, the tax rate τ, the depreciation rate for R&D capital δ, the interest rate r, as well as all the past history of the firm, but not the tax parameters of the current R&D cost function h. When $h(.)$ is linear in R_t (the normal situation without the R&D tax credit) and under suitable convexity and concavity assumptions on $S(\cdot)$ and $\Phi(\cdot,\cdot)$, a solution to this model will exist.[1] With the R&D tax credit, however, h has a complex step function form:

$$\begin{aligned} h(R_t, R_{t-1}, R_{t-2}, R_{t-3}) &= (1 - \tau)R_t - \eta_t \rho_t (R_t - B_t) && \text{if } B_t < R_t < 2B_t \\ &= (1 - \tau)R_t && \text{if } R_t < B_t \\ &= (1 - \tau)R_t - \eta_t \rho_t (R_t/2) && \text{if } R_t > 2B_t \end{aligned}$$

where $B_t = (R_{t-1} + R_{t-2} + R_{t-3})/3$ is the base level of R&D expenditure.[2] η_t is the fraction of qualified expenditures and ρ_t is the statutory credit rate. Although it is not possible to solve the model completely in this case, the

[1] The alert reader will observe that some of the estimates in the paper imply an optimal R&D policy that may not satisfy the assumptions needed to guarantee that the problem does not blow up at infinity. Either the discount rate r must be large enough to prevent that from happening, or the optimal R&D trajectory must exhibit something less than pure random walk behavior in practice. The first differenced estimates suggest that this is indeed the case once we control for permanent unobserved differences across firms, but of course these estimates require that we give up any notion of a representative firm in our modeling.

[2] The exposition here is for the R&D tax credit which was in place for the 1982–1988 period. A similar analysis, suitably modified for changes in the tax code, applies for 1981 and 1989–1991.

Euler equation for optimal R&D investment is a slightly modified equation (5):

$$E_t \left\{ \frac{1-\delta}{1+r} [\frac{\theta_{t+1}}{1-\tau} + \Phi_R(t+1)] - [\frac{\theta_t}{(1-\tau)} + \Phi_R(t)] - \Phi_G(t) + S'(t) \right\} = 0$$

$\Phi_R(t)$ and $\Phi_G(t)$ denote the partials of the adjustment cost function with respect to R_t and G_t in an obvious notation. θ_t is the marginal cost of R&D investment at time t, including its effects on the future cost of R&D spending through the computation of the base:

$$\theta_t = \sum_{s=0}^{3} (1 + r)^{-s} h_{s+1}(R_{t+s}, R_{t+s+1}, R_{t+s+2}, R_{t+s+3})$$

h_{S+1} denotes the partial derivative of the cost function $h(.)$ with respect to argument $(s + 1)$. Equations (6) and (7) in the paper give the exact form of θ_t, derived from the expression for h given above.

To obtain the estimating equation actually used for the estimates in Tables 5a and 5b, I write the adjustment cost function as in equation (8) and the sales function as

$$S(G_t) = A\, G_t^{\gamma} \qquad 0 < \gamma < 1$$

where A contains all other inputs; if S is a Cobb-Douglas function of these inputs, and they are all variable (can be freely adjusted to optimal levels given G_t), then there is no loss of generality in suppressing the other inputs. Even if the firm is not a price-taker, so that sales are not directly proportional to output, this equation will remain appropriate if the demand function is constant elasticity.

The set of assumptions that justify the use of this equation are not realistic, but provide a simple first-order approximation to the problem in order to make it tractable. The most obvious weakness is the failure to treat ordinary investment in parallel with R&D, because it is both subject to adjustment costs and interacts with the output of research (Bernstein and Nadiri 1988, Hall and Hayashi 1988, Lach and Schankerman 1989); a full tax treatment of investment is beyond the scope of the present paper and is left to future work (and the past work of others).

Cobb-Douglas production together with equations (8) and the Euler equation given above yield the following version of equation (9):

$$E_t \left\{ \frac{1-\delta}{1+r} [\frac{\theta_{t+1}}{1-\tau} + \phi \frac{R_{t+1}}{G_{t+1}}] - [\frac{\phi_t}{(1-\tau)} + \phi \frac{R_t}{G_t}] + \frac{\phi}{2} (\frac{R_t}{G_t})^2 - \gamma \frac{S_t}{G_t} \right\} = 0$$

Because τ, r, and δ are known at time t, this equation can be written in the form actually estimated. Note that the appropriate instruments for expectational reasons are things that the firm knows at the beginning of period t, including those that will help predict the tax prices at t and $t + 1$. I have chosen a more restrictive set of instruments dated lag 2 and earlier because of the measurement error issues, but the law of iterated expectations means that my estimates will also be consistent.