ELSEVIER

Research Policy 29 (2000) 449–469

research policy

www.elsevier.nl/locate/econbase

How effective are fiscal incentives for R&D? A review of the evidence

Bronwyn Hall [a,b,c], John Van Reenen [c,*]

[a] UC Berkeley, Berkeley, CA, USA
[b] Nuffield College Oxford and NBER, UK
[c] Institute for Fiscal Studies, University College London and CEPR, 7 Ridgmount Street, London, WC1E 7AE, UK

Abstract

This paper surveys the econometric evidence on the effectiveness of fiscal incentives for R&D. We describe the effects of tax systems in OECD countries on the user cost of R&D — the current position, changes over time and across different firms in different countries. We describe and criticize the methodologies used to evaluate the effect of the tax system on R&D behaviour and the results from different studies. In the current (imperfect) state of knowledge we conclude that a dollar in tax credit for R&D stimulates a dollar of additional R&D. © 2000 Elsevier Science B.V. All rights reserved.

JEL classification: H32; 031; O38
Keywords: Tax credits; R&D; international

1. Introduction

Economists generally agree that the market will fail to provide sufficient quantities of R&D as it has some characteristics of a public good. But how should policy bridge the gap between the private and social rate of return? A tax-based subsidy seems the market-oriented response as it leaves the choice of how to conduct and pursue R&D programs in the hands of the private sector. There are several drawbacks to this tool, however, compared with government financing and/or conducting the R&D program directly (see Klette et al., 2000). Perhaps the primary objection is that fiscal incentives are simply ineffective in raising private R&D spending — the response elasticity is so low it would take a huge tax change to generate the socially desirable level of spending. This was the conventional wisdom among economists until recently, so it is the key focus of this paper. We address the issue of how governments (sometimes inadvertently) have used the tax system to promote R&D, how researchers have evaluated these effects, and what are the results of their evaluations.

There are other objections to the use of the tax system to which we will be paying less attention. First, the projects that should be promoted from a social view are those with the largest gaps between the social and private return. Yet private sector firms will use any credits to first fund R&D projects with the highest private rates of return. In principle the state could do a lot better by targeting the projects with the highest spillover gap. In practice this maybe very hard to deliver because of the intrinsic uncertainty of knowledge creation and because of the

* Corresponding author. E-mail: jvanreenen@ifs.org.uk

PII: S0048-7333(99)00085-2

tendency of states to reward lobbyists and bureaucrats rather than take the optimal decisions. [1] In the face of pervasive government failure to implement the optimal subsidy policy, tax credits appear more attractive.

Using the tax system to stimulate R&D is far from the ultimate panacea for failures in the market for knowledge. Implementation in the existing political and tax environment has meant that there are frequent changes in the fiscal incentives faced by firms that affect the costs of performing R&D in different ways for different companies at different times. This heterogeneity is a burden for companies and policy makers but is a boon for social scientists. A long-standing problem in the investment literature is the intractability of finding exogenous variation in the user cost of capital. The heterogeneity across firms and time in the cost of capital for this type of investment has the potential to help identify parameters of the underlying R&D investment demand equation. The frequent changes of government policy offer a rare opportunity to generate some exogenous movement in the price of R&D (even across firms) that could be used to identify a key part of the neoclassical model. What's bad for the economy may be good for the econometricians!

The paper is structured as follows. In Section 2 we examine the tax treatment of R&D in an international context and introduce the major issues. In Section 3 we critically outline the methodologies researchers have used to examine the effects of tax incentives on R&D. In Section 4 we present the survey of results and in Section 5 we offer some concluding comments.

2. The tax treatment of R&D across countries

2.1. The current position

The treatment of R&D by the tax system various extensively between countries and over time. Table 1, which is drawn from many sources, summarizes the position in approximately 1995 to the best of our knowledge. [2] The second column of the table attempts to give the definition of R&D that is used for the purpose of the tax credit, which is often somewhat more restrictive than the Frascati manual (OECD, 1980) definition, but not always. The next two columns give the rates at which non-capital R&D and capital R&D are depreciated for tax purposes. One hundred percent means that the quantity is expensed. In most cases it is also possible to elect to amortize R&D expenditure. This might conceivably be an attractive option if operating loss carryforwards are not available (to use the R&D expense as a deduction even if no current tax is owed), but in most cases tax losses can be carried forward and back (see column 7).

Given that R&D capital expenditure is typically only 10–13% of business R&D, and that the business R&D–GDP ratio is typically 1–2% (OECD, 1984), implying an R&D capital equipment–GDP ratio of 0.1–0.2%, a remarkable amount of time has been spent in many of these countries tinkering with the expensing and depreciation rules for capital equipment used in R&D activities. [3] Although almost all countries (except for the UK) treat this kind of capital expenditure somewhat like ordinary investment, many have used complex speeded-up depreciation schemes at one time or another to give a boost to a R&D capital equipment investment; this can be often be justified by the simple fact that the economic life of this kind of specialized equipment is likely to be shorter than that for other types of capital. Frequently the depreciation involved is also

[1] On this point, see Cohen and Noll (1991) for discussion of the issue and a series of examples drawn from the U.S. experience of the past 30 years. They demonstrate that large federal R&D projects have frequently been continued well past the point where expected costs exceeded expected benefits due to the existence of stakeholders that had legislative influence.

[2] Sources include Asmussen and Berriot (1993), Australian Bureau of Industry Economics (1993), Bell (1995), Bloom et al. (1998, 2000), Griffith et al. (1995), Harhoff (1994), Hiramatsu (1995), Leyden and Link (1993), McFetridge and Warda (1983), Seyvet (1995), Warda (1994), and KPMG (1995).

[3] In addition to the features of the tax system targeted toward R&D equipment expenditures at the federal level in many countries, in many U.S. states there is a special sales tax provision which exempts firms from paying sales tax on purchases or repairs of this kind of equipment. This amounts to an additional tax credit of about 4–8% in the states that have this provision.

subject to the R&D tax credit. Normally buildings or plant for use by an R&D laboratory do not participate in these schemes.

Columns 5 and 6 characterize the tax credit, if there is one. The rate and the base above which the rate applies are shown; when the base is zero, the credit is not incremental, but applies to all qualifying R&D expense. At the present time, it appears that only France, Japan, Korea, Spain, the US, and Taiwan have a true incremental R&D tax credit, and they each use a slightly different formula for the base. Canada has a non-incremental credit and Brazil has a non-incremental credit that is restricted to computer industry research. Column 9 shows that many countries also have provisions that specially favor R&D in small and medium-sized companies. In France, for example, this takes the form of a ceiling on the credit allowed that is equal to 40 million francs in 1991–1993 (approximately US$6.7 million). The effect is to tilt the credit toward smaller firms, whereas direct R&D subsidies in France go to large firms to a great extent (Seyvet, 1995). An exception to this rule is Australia, which has a minimum size of research program to which the tax preference of 150% expensing applies: US$20,000. This seems to be related more to the administrative cost of handling the R&D tax concession than to any policy decision (Australian Bureau of Industry Economics, 1993; Bell, 1995).

Columns 10 and 11 give any differences in tax treatment that apply to R&D done abroad by domestic firms or R&D done in the country by foreign-owned firms. For the first type of R&D, any special incentives (beyond 100% deductibility) will typically not apply, except that up to 10% of the project cost for Australian-owned firms can be incurred outside Australia. For the second type of R&D, it is frequently difficult to tell from the summarized tax regulations. In Korea and Australia, foreign firms do not participate in any of the incentive programs. In the US and Canada, they are treated like domestic firms, except that they do not receive an R&D grant in Canada when their tax liability is negative.

Column 8 details whether the incremental tax credit is treated as taxable income, that is, whether the expensing deduction for R&D is reduced by the amount of the tax credit. Whether or not this is true typically has a major effect on the marginal incentive faced by a tax-paying firm, but it is somewhat hard to ascertain in many cases whether this feature applies.

2.2. Changes over time

Reforms of systems of taxing corporate income over the past decade have tended towards lowering statutory rates and broadening the tax base. What has happened to the tax treatment of R&D over that time period? This section documents some of the main changes in the tax treatment of R&D in eight countries over the period 1979 to 1994 (see Bloom et al. (1998, 2000) for more details). It is worth noting that the cost of R&D figures reported in this section are calculated assuming that the R&D investment qualifies for any credit, that the amount of credit is not constrained by any capping rules and that the firm has sufficient tax liability against which to offset the credit. In the next section we investigate how the various credits affect firms in different positions.

The following assumptions are made concerning the type of R&D investment to be analysed. We consider a domestic investment, financed from retained earnings, in the manufacturing sector and divided into three types of asset for use in R&D — current expenditure, buildings, and plant and machinery. An important assumption in the modelling strategy used here is that current expenditure on R&D is treated as an investment — that is, its full value is not realised immediately but accrues over several years. Current expenditure on R&D is assumed to depreciate at 30% a year, buildings at 3.61% and plant and machinery at 12.64%.

Fig. 1 shows how the tax treatment of R&D has changed over time. This graph shows the tax component of the user cost of R&D for a typical R&D [4] investment in Australia, Canada, France and the US. These are the four countries that had the most gener-

[4] ‘‘Typical’’ means a domestic investment financed from retained earnings for a firm which is not tax exhausted or hitting any maximum tax credit caps.

Table 1
The tax treatment of R&D around the world

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Country (date enacted)	Definition of R&D for tax credit	R&D deprecia-tion rate	R&D capital depreciation rate	Tax credit rate	Base for incremental tax credit	Carryback (CB) and carryforward (CF)	Credit taxable?	Special treatment for SMEs	Foreign R&D by domestic firms	R&D by foreign films
Canada (1960s)	Frascati, excl. soc sci. marketing, routine testing, etc.	100%	100% or 20% DB, 20% ITC, not buildings	20%	0	3 yr CB, 10 yr CF	yes	40% to R = C$200 K grant if no tax liab., 35% cap eq ITC to $2 M	expense no ITC, etc.	20% only?
France (1983)	Frascati, incl. patent dep. contract R, excl. office expenses & support personnel incl. upgrades, SW, overhead	100% or 5 yr cap.	3-yr SL (not buildings) accelerated	50%	[R(−1) + R(−2)]/2 (real)	5-yr CF, 5-yr for OL, TC refunded	no (recaptured)	yes TC < 50MFF	no accel dep unless cons. no credit	?
Germany	Frascati, incl. Develop-ment, improvements, software	100% cap. If acq.	30% DB, 4% SL — bldgs, cash grants?	none	NA	1/5 yr	NA	assistance via cash grant/ITC		25% on royalties
Italy	Frascati, incl. Software	100% or 5 yr cap.	accelerated	none	NA	NA	?	yes, ceiling		
Japan (1966)	Frascati, incl. depreciation of P&E, deferred charges benefit > 1 yr, incl. Software	100% or 5 yr cap.	accelerated 5% TC — bldgs	20% (max at 10% tax liab.)	max R since 1966	5-yr usual but credit limited to 10%	no	6% R instead (cap < Y100 m), 6% for envir./ disease	6% credit for coop with foreign labs	20% on royalties
UK	no special definition; treated as an expense, however	100%	100% if ''scientific research''	none	NA	5-yr CF	NA			25% on royalties
US (July 1981)	excl. contract R (for doer), rev. engineering, prod. improv., 35% contract R	100%	3-yr., 15-yr. for bldgs	20%	avg of 84–88 R	3/15 yr	yes	R&D to Sales 3% for startups	not eligible	same as domestic
Australia (July 1985)	Frascati, excl. soc sci, some testing, marketing overhead, software	150%	3-yr SL (not buildings)	none	NA	3/10 yr	NA	ceiling; reduced credit for small R&D programs	up to 10% of project cost incl in 1995?	no special provisions
Austria	Dev. and improv. of valuable inventions	105%	accelerated	none	NA	5-yr CF	NA			
Belgium	incl. Software	100% or 3 yr cap.	3-yr SL 20-yr — bldgs	none	NA	5-yr CF	NA	10–15% addl capital deduction		

Brazil	R&D in computer ind.	100%	like investment	none 100% of comp.	NA	4-yr CF				
China (PRC)	NA			none						
Denmark	Special tech programmes with EC researchers	100%?	100%	?	?	5-yr CF	?			
India	scientific research or knowhow	100%	100% except land	none	NA	?	NA		30–50% on royalties	
Ireland	scientific research incl. software	100%	100% (not related), 15% otherwise	up to 400%?	??	?	??	TC ceiling of 525 000	27% on royalties; tax treaties	
Korea	experimental and research expenditure	100%	18–20% deprec, 5.6% — bldgs	10% 25%	0 avg of last 2 yrs	?	no	yes; special rules for startups	10–16% on royalties	no special provisions
Mexico		100%	3-yr SL, 20-yr — bldgs	none	NA	?	NA			
Netherlands (1994)	Wages of R&D leading to prod. dev. (not services)	100% or 5 yr cap.	like investment	12.5–25%	0	8-yr CF	no	yes; ceiling on ITC max on R&D wages	no tax on royalties	
Norway	prod. dev., capitalized knowhow	100% cap if prod.	like investment	none	NA	10-yr CF (res. reserve)	NA		no tax on royalties	
Portugal	usual	100% or 3 yr cap.		none	NA	?	NA		does not apply	0–27% on royalties
Singapore	excl. soc. sci., quality control, software	cap. except some R&D	deprec. as usual	addl deduction (200%)	NA	?	NA	yes		
South Africa	scientific research development of tech.	100% for R cap. for D	25% dep for cap	none	NA	?	NA			
Spain	excl. routine prod. improve. incl. software	amortize over 5 yrs	100% or depreciate	15%/30%, 30%/45% on F.A.	avg of last 2 yrs (for higher rate)	5-yr CF-OL, 3-yr CF-TC	NA		5–25% on royalties	
Sweden (discontinued 1984)		100%	30% DB, 4% SL — bldgs	none	NA	tax liability	NA			
Switzerland	none incl. software	100% or 5 yr cap.	like investment	subcontracted research	?	2-yr CF	?		35% on royalties	
Taiwan	usual	100%	deprec. as usual	15% 20%	2% revenue, 3% revenue	4-yr CF	NA		3.75–20% on royalties	

Notes to Table 1:
1. Situation in 1995 unless elsewhere specified.
2. Abbreviations: R = research, NA = not applicable, KC = incremental tax credit, TC = tax credit.

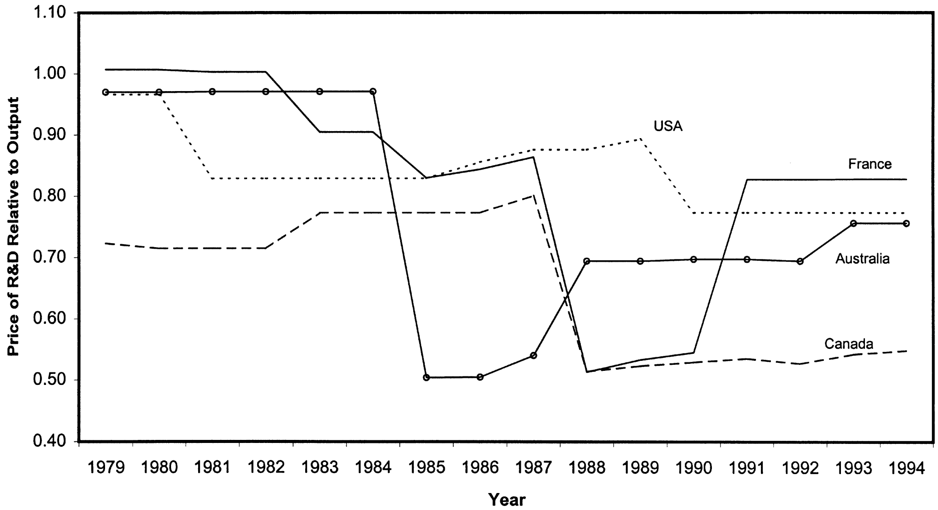

Fig. 1. Tax component of R&D user cost — four most generous countries. Source: Bloom et al. (2000).

ous treatment of R&D. The tax component user cost measures the generosity of the tax system in subsidising R&D (see Appendix A). In general, the full user cost depends on differential inflation and interest rates, but we have set the real interest rate to be 10% across all countries and years to highlight the tax element of the user cost. The user cost is weighted across assets (90% current expenditure, 3.6% buildings, and 6.4% plant and machinery). A value of unity signals that the tax system is broadly neutral with respect to R&D. This can occur if all R&D was fully written off and there were no special tax credits.

Taking any year in isolation, it is clear that large differences exist among countries, a feature highlighted in previous studies. It appears that Canada has the most generous treatment of R&D, except during 3 years in the mid 1980s when Australia gave a larger subsidy. Furthermore, in all of these countries the tax treatment of R&D has become *more* generous since the early 1980s, although there has been considerable turbulence. The relative position of countries has moved around and there are substantial changes in the tax wedge on R&D due to changes in tax policies. The mid to late 1980s was a period of particular change. This variation illustrates the difficulty for firms considering long term investment plans, that there may be considerable uncertainty about the permanence of fiscal incentives.

The reasons for the periods of large change in the cost of R&D vary across countries. In Australia, the large drop in 1985 was due to the introduction of a 150% ''superdeductibility'' for R&D. The subsequent increase was due to the lowering of Australia's statutory rate of corporation tax. The generosity of the Canadian system is driven by the fact that the credit rate is relatively high on the incremental amount of R&D. The fall in the cost of R&D in 1988 was precipitated by the introduction of a second credit in Ontario (the province which we model here). In France, the introduction of the credit in 1983 had much less effect than the redefinition of the base (from a moving base to a fixed base and then back again) which occurred between 1987–1990. Similarly in the USA, the base re-definition in 1990 had as large an effort as the introduction of the credit in 1981. These points illustrate that the statutory credit rate is not of over-riding importance to the cost of R&D. The design and implementation of the schemes (such as the definition of the base) and the effects of other parts of the tax system (such as the statutory tax rate) are at least of equal importance in explaining the trends over time.

Fig. 2 shows the tax wedge in the four less generous countries. In these countries the tax systems are broadly neutral to R&D (i.e., the tax wedge is close to zero). There have not been many changes in the tax treatment of R&D in these countries over

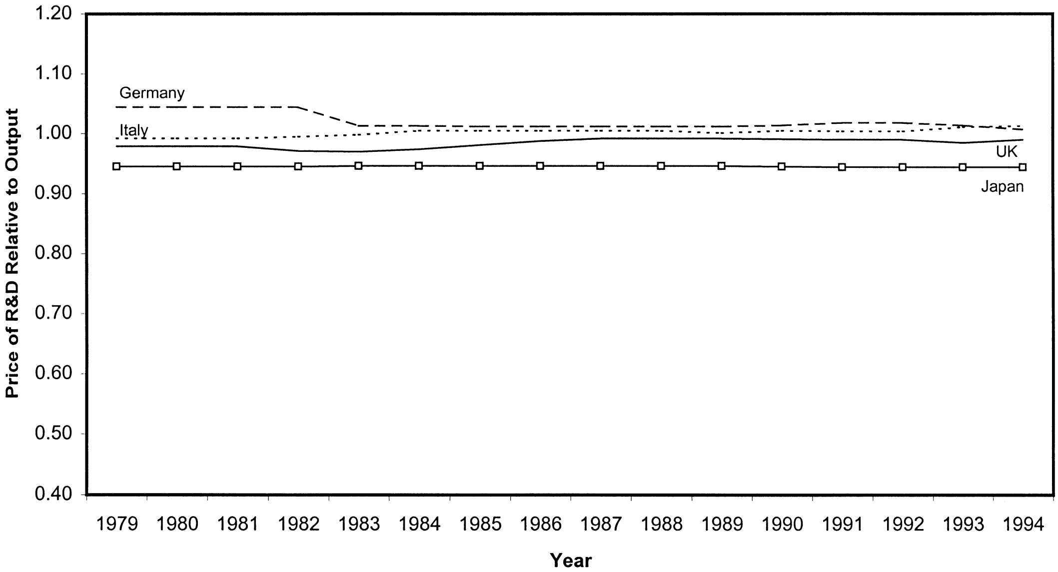

Fig. 2. Tax component of the user cost of R&D — four least generous countries. Source: Bloom et al. (2000).

this period. Japan occupies an intermediate position, however, as the only country in this group which has an R&D tax credit although the UK does also give an allowance for R&D capital expenditure.

Another striking feature of Figs. 1 and 2 taken together is that the range of the user costs at the end of the period is greater than at the start. In 1979 the mean effective marginal tax wedge on the typical

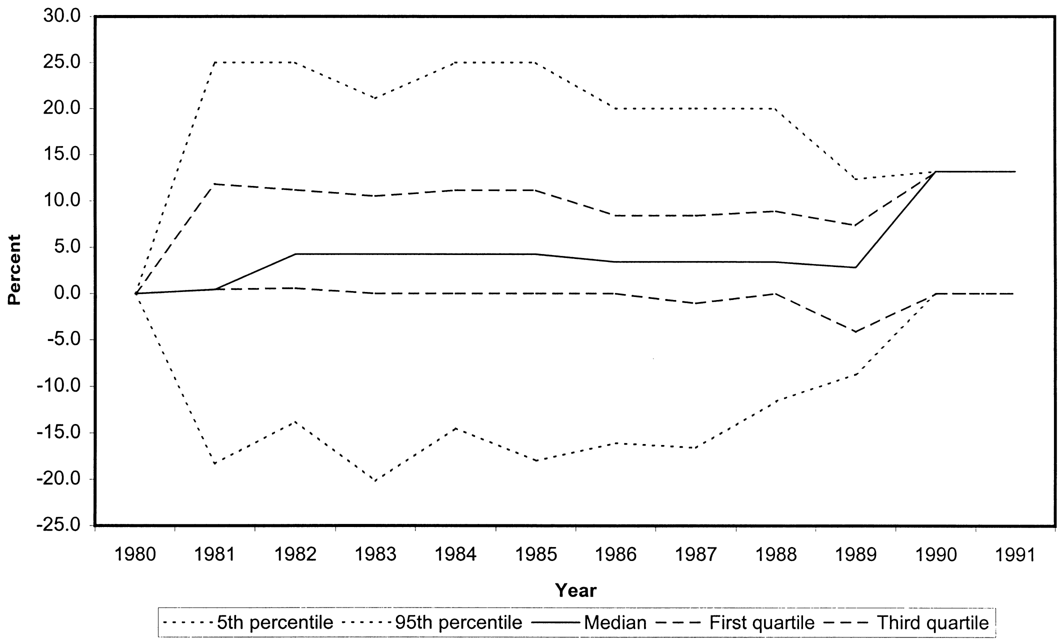

Fig. 3. Distribution of the effective R&D tax credit — U.S. Source: Hall (1993).

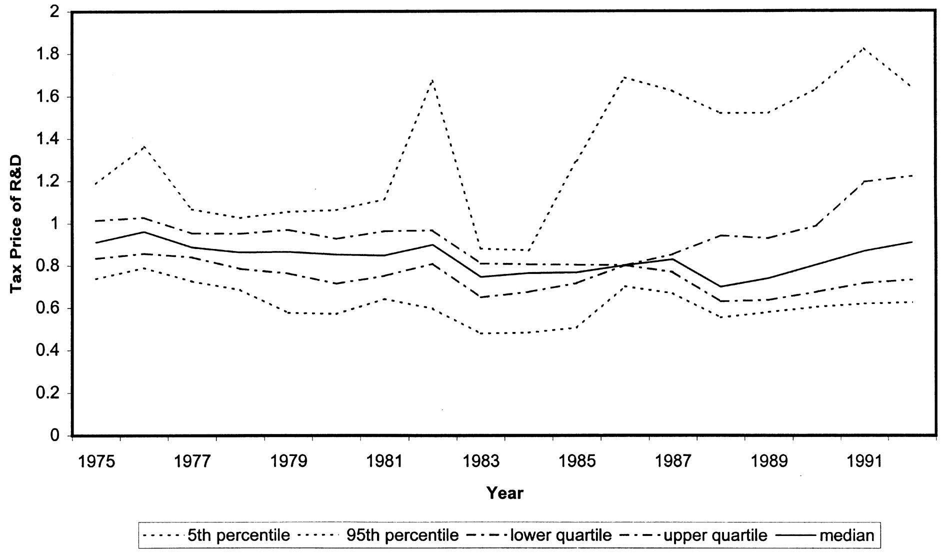

Fig. 4. Distribution of the effective R&D tax credit — Canada. Source: Dagenais et al. (1997).

R&D investment was 0.953 with a standard deviation of 0.098. By 1994 the mean had fallen to 0.857 and the standard deviation increased to 0.163.

2.3. Heterogeneity of the effects of the tax system

One of the striking findings of the flourishing of micro-economic studies in the last two decades is the huge heterogeneity between different firms. The way in which the R&D tax credit creates heterogeneous and often perverse incentives has been a key feature of the debate on the (un)desirability of R&D tax credits. The heterogeneity emerges in many ways. First, unless there is a full refund then many firms will not be able to use the full value of the tax credit because they do not have sufficient taxable profits (e.g., young firms or firms in recession). Carryforwards and carrybacks will compensate for this to an extent depending on interest rates and expectations of future taxable profits. Second, there are usually caps limiting the maximum credit available. Third, the definition of the base will affect firms in different ways. A moving base will mean that firms who are intending to increase their R&D may be put off because their current increases increase the size of the base which will limit their future tax rebates (Eisner et al., 1982).

To illustrate the importance of heterogeneity, Fig. 3 shows the distribution of the user cost of R&D in the US over time (The user cost is defined slightly differently from Figs. 1 and 2 – see Hall, 1993). There is considerable heterogeneity for most of the period. The reduction in the 1990s is due to moving from a moving base to a fixed base in 1989. A similar graph for Canada is given in Fig. 4. This variation between firms is almost certainly an additional source of uncertainty facing firms. It offers a potential source of identification in firm panel studies of R&D.

3. Effectiveness of the R&D tax credit

There are two approaches to evaluating the effectiveness of any tax policy designed to correct the insufficient supply of a quasi-public good. The first asks whether the level of the good supplied after the implementation of the policy is such that the social return is equal to the social cost. In this situation, that would involve comparing the marginal return to industrial R&D dollars at the societal level to the opportunity cost of using the extra tax dollars in another way, for example, in deficit reduction. This is a very tall order, and policy evaluation of the tax credit usually falls back on the second method, which is to compare the amount of incremental industrial R&D to the loss in tax revenue. The implicit assumption in this method is that the size of the subsidy has been determined and that the only question to be answered is whether it is best administered as a tax credit or a direct subsidy. Obviously, this kind of benefit–cost ratio is only very loosely connected with the magnitude of the gap between the social and private returns to R&D, if at all. It might be that the social return from additional industrial research is very high. If it is very high one may be willing to give up more tax dollars than the actual research induced by the tax subsidy. On the contrary, if the social return is only slightly higher than the private return, lowering the cost of research might cause the firm to do too much. [5] In this case, even though the tax credit induces more industrial R&D than the lost tax revenue, it would not be a good idea, because one could have spent that tax revenue on some other activity which had a higher social return. Fortunately, the available evidence on the social return to R&D suggests that the first case is more likely than the second.

Most evaluations of the effectiveness of the R&D tax credit have been conducted using the second method, that is, as benefit–cost analyses. We need to calculate both the amount of R&D induced by the tax credit, and computing the costs requires estimating how much tax revenue is lost due to the presence of the credit. The ratio of these two quantities is the benefit–cost ratio; if it is greater than one, the tax credit is a more cost-effective way to achieve the given level of R&D subsidy; if it is less than one, it would be cheaper to simply fund the R&D directly. This part of the paper critically reviews the methodology underlying these evaluations and surveys the resulting evidence, including the small number of studies that have been conducted using data from outside the US.

[5] Some government policies towards R&D are explicitly aimed at reducing duplicative R&D — for example, in the US, government sponsored consortia such as SEMATECH, as well as the antitrust exemption contained in the National Cooperative Research Act of 1982.

3.1. Costs of R&D tax support

The first ingredient in doing a benefit–cost analysis of the tax credit is the computation of total cost. The total social cost consists of the net tax revenue loss due to the credit plus the costs of administering it, both to the firm and to the taxing authority. In practice, the cost computed has been simply the gross tax credit claimed. At best this has been done by simply adding up the credits claimed by the firms that use the credit (Mansfield, 1986; Hall, 1993), sometimes adding in the unused credits that have been used to offset prior-year liabilities (U.S. General Accounting Office, 1989). Occasionally estimates have been produced relying only on representative or average firm behavior; this method is likely to produce erroneous results given the extreme heterogeneity in the data. Either way, this type of analysis ignores the fact that the existence and use of the R&D tax credit may have implications for the overall tax position of the firm, so that the net change in tax revenue because of the credit is not captured by simply adding up the credits. It is likely that these other effects are relatively small, but by no means certain.

The second omission in the conventional computation is the administrative cost of the tax credit. The GAO Study of 1989 (U.S. General Accounting Office, 1989), updated in 1995, makes it clear that these costs can be high, but offers no estimate of their magnitude. Difficulties arise in two areas: the definition of eligible R&D, which typically requires a distinction between routine and innovative research, and may be more restrictive than the definition used by the firm's accountants, and the performance of research by outside subcontractors. For example, the U.S. Internal Revenue Service appears to have taken the position that the tax credit should flow to the organization that will pay for the R&D ''in the normal course of events'', rather than to the organization that bears the risk of the investment. Stoffregen (1995) argues that these ambiguities in interpretation of the law also impose costs on the firms, in that they will be unsure whether the R&D they are undertaking will fall within the area delimited by the tax regulations as legitimate qualified expenditures. The GAO reports that almost 80% of returns claiming R&D credits are audited in the US with an average net adjustment downward of about 20% of the credits claimed.

3.2. The benefits of R&D support: evaluation methods

Can the R&D tax credit stimulate as much research per dollar as funding the R&D directly? Conceptually, measuring the amount of R&D induced by a tax credit is a ceteris paribus exercise, in which we attempt to ask the question: ''How much more R&D did firms do given the existence of a tax credit than they would have done if there had been no credit?'' The counterfactual is never observed, and researchers fall back on a variety of methods to try to estimate the level of R&D without the subsidy. We consider three evaluation methods.

3.2.1. Event and case studies

Event studies typically rely on the assumption that the event being studied (such as the introduction of a tax credit) is a surprise to the economic agents it affects. They are usually conducted using financial market data, although this is not necessary. The method involves comparing behavior before a surprise change in policy is announced with behavior after the announcement in order to deduce the effect of the policy change. In this instance, such a comparison can take the form of comparing the market value of R&D-oriented firms before and after the tax credit legislation was considered and passed, or of comparing R&D investment plans for the same time period before and after the legislation. (An example of the former method is Berger, 1993 and of the latter is Eisner, as reported in Collins, 1983.) A problem with many of these studies is that other events are not conditioned out (such as demand growth accompanying the policy change).

A case study is essentially a retrospective event study. You simply ask the senior managers of industrial firms how their R&D spending has been affected by the introduction of an R&D tax credit (for example, Mansfield, 1986). These are often combined with an econometric analysis (e.g., Mansfield and Switzer, 1985a,b who looked at 55 Canadian firms). These have the advantage that (in principle) the manager controls for other factors when she answers the question. The main problem is that managers may not give the right answer to the question, for subjective or perceptual reasons. [6] Furthermore, event and case studies tend to be focused on rather small samples of firms, due to the cost of collecting the data to perform them.

3.2.2. Natural experiments: R&D demand equation with a shift parameter for the credit

Here one constructs as well as possible an equation that predicts the level of R&D investment (r_{it}), $t=$ time as a function of past R&D, past output, expected demand, perhaps cash flow and price variables, and so forth (different studies have different conditioning variables — call these x_{it}). A dummy variable is included (C_{it}), equal to one when the credit is available and zero otherwise. For example:

$$r_{it}=\alpha_0+\beta C_{it}+\gamma' x_{it}+u_{it} \tag{3.1}$$

Where u_{it} is a stochastic error term. The magnitude of the estimated coefficient of the dummy (β) is equal to the amount of R&D induced by the presence of the credit. If this exercise is conducted using firm-level data ($i=$ firm), the best method is to measure the availability of the credit at the firm level, that is, taking account of the usability of the credit. If it is conducted at the macro-economic or industry level, the identification of the credit effect will generally come from the variation in R&D demand over time ($C_{it}=C_t$) (examples: Baily and Lawrence, 1992; Swenson, 1992; Berger, 1993; Eisner et al., 1983; McCutchen, 1993). The advantage of this method is its relative simplicity; it eliminates the need to perform the relatively complex computations to determine the actual level of the tax credit subsidy for each firm. The disadvantage is that the measurement is relatively imprecise, because there is no guarantee that all firms are facing the same magnitude of credit at any given point in time. In fact, we have seen how great the variation in the user cost has been after the credit was introduced in Fig. 3 (for the US) and Fig. 4 (for Canada). In addition, if the variation in the credit dummy is over time, it is

[6] There is a general tendency in surveys for managers to focus on their firm's (or their own individual) idiosyncratic brilliance rather than general features of the economic environment as the source of positive change.

very possible that other forces which increase aggregate industrial R&D spending (such as global economic conditions, trade, etc.) and that are not included in the R&D equation may lead to a spurious conclusion about the effectiveness of the tax credit. In other words the credit dummy is not separately identified from a set of time dummies.

3.2.3. Quasi-experiments: price elasticity estimation

This method is similar to the previous method, in that an R&D equation that controls for the non-tax determinants of R&D is estimated, but in this case a price variable — the user cost of R&D — that captures the marginal cost of R&D is included in the equation. As with Eq. (3.1) lags may be introduced into the explanatory variables. The estimated response of R&D to this price variable is converted to an elasticity of R&D with respect to price. If the price variable includes the implicit subsidy given by the tax system to R&D, this is a direct measure of the response of R&D to its tax treatment (examples: Hall, 1993; Dagenais et al., 1997).

$$r_{it} = \alpha_0 + \beta\rho_{it} + \gamma' x_{it} + u_{it} \tag{3.2}$$

Even if the price variable does not contain a measure of the tax subsidy, it is possibly to use the measured elasticity of R&D with respect to price to infer the response induced by a tax reduction of a given size. This involves the step of estimating the effect of a given policy change (such as an increase in the credit rate on the user cost of R&D) which is a mechanical exercise given one's definition of the price. The second step is using the estimates of the model to predict what will happen to R&D following a change in the price. In the most simple case, holding all else constant, if we estimate a price elasticity of -0.5 and the effective marginal R&D tax credit is 0.05, or a 5% reduction in cost, then the estimated increase in R&D from the tax credit will be 2.5% (examples: Collins, 1983; Mansfield, 1986; U.S. General Accounting Office, 1989). Of course this is too partial, a reduction in costs will also affect the firm's output and if output is in the equation, the full effects are likely to be larger as output will rise as costs fall. There will also be possible spillover effects, and so on. However, researchers have tended to focus on the output–constant price effects (see below for more ''structural'' approaches).

The advantage of this method is that it is better grounded in economic theory and estimates the price response of R&D directly. Thus it will be somewhat more accurate than the previous method. Using the tax price elasticity of R&D (the first variant) has a couple of disadvantages: First, because the firm benefits directly from the amount of R&D qualified to receive the tax credit, it is possible that it will relabel some expenses as R&D (legitimately or illegitimately) and the ''true'' induced R&D will therefore be an overestimate. Secondly, and perhaps most seriously, because the tax credit depends on a variety of firm characteristics, such as its operating loss position, how much foreign income it repatriates, and so forth, the R&D investment level and the tax price faced by the firm are simultaneously chosen, and ordinary regression methodology is inappropriate in this situation. For this reason, some researchers have relied on instrumental variables to estimate the price elasticity, with both the attendant loss of precision in estimation and problems with finding appropriate instruments to identify the endogenous variable. [7]

The second variant of the quasi-experimental approach suffers from deeper disadvantages. Absent variations in tax treatment across firms and time, one is forced to use a constructed R&D price deflator as the price variable in an R&D demand equation. These deflators typically are a weighted average of R&D inputs, of which around half is the wages and salaries of technical personnel, and the other half is some kind of research materials and equipment index. The only real variation in this variable is over time. This is a very thin reed on which to rest the estimation of the price elasticity of R&D demand; the estimates will depend strongly on the other time-varying effects included in the model.

We finish this section with some general methodological problems. First, the theoretical justification of Eq. (3.2) is unclear. Some writers have argued for a much more ''structural'' approach to the R&D equation. This is more easily said than done, how-

[7] See Hall (1993) and Hines (1993) for examples. Possible instruments are the lags of the user cost variables and the industry level deflators, as well as lagged values of firm characteristics in the case of micro data.

ever. Structural investment models for physical capital have had a poor record of success in empirical testing whether of q-models, Euler equations or Abel–Blanchard variety (see Bond and Van Reenen, 1998, for a survey). Although various attempts have been made to estimate these more structural forms none have been conspicuously successful (e.g., Hall, 1993; Harhoff, 1994). [8] A simple way of motivating the R&D investment equation is to treat it symmetrically to fixed investment. If the production function can be approximated as a CES (constant elasticity of substitution) then the first-order condition under perfect competition would have the following form

$$g_{it} = \alpha_0 + \beta\rho_{it} + \gamma y_{it} + u_{it} \tag{3.3}$$

where g_{it} = the log(R&D stock), y_{it} = log(output) and ρ_{it} = log(user cost of R&D). Under this model β = the Hicks–Allen elasticity of substitution. Constant returns implies that $\gamma = 1$. The stock is generally calculated using the perpetual inventory method where $G_t = R_t + (1-\delta)G_{t-1}$, capital letters denoting the levels (not logs) of g and r, and δ is the knowledge depreciation rate. Unfortunately, unlike physical capital there is little information upon which to base the initial condition in constructing this measure.

Several studies specify the R&D equation in terms of a stock rather than a flow measure (e.g., Shah, 1994; Bernstein, 1986). It is important to be aware of this difference when examining the empirical studies as the stock will be much higher than the flow. However, when the equation is specified in logarithms (as it usually is) then the difference is not so clear. To see this assume that the R&D stock grows at rate υ_i, we have $G_{it} = (1+\upsilon_i)G_{i,t-1}$ so that

$$R_{it} = (\delta + \upsilon_i)G_{i,t-1} = \left(\frac{\delta + \upsilon_i}{1+\upsilon_i}\right)G_{it}$$

and

$$r_{it} = \ln\left(\frac{\delta + \upsilon_i}{1+\upsilon_i}\right) + g_{it} = -\eta_i + g_{it}$$

Substituting this equation into Eq. (3.3) gives

$$r_{it} = \alpha_0 + \beta\rho_{it} + \gamma y_{it} + \eta_i + u_{it} \tag{3.4}$$

This implies that we have to allow for firm fixed effects in the R&D equation, but that otherwise the estimates will be approximately the same, whether we use the log of the stock of R&D or its flow as the dependent variable. [9] That is, as long as R&D is growing at approximately a constant rate at the firm level and we include fixed effects in the R&D equation, the interpretation of the coefficients is the same as it was in Eq. (3.3).

A deeper problem relates to the adjustment cost function of R&D. ''Reduced form'' approaches will usually use a general dynamic form of Eq. (3.4) to capture these. The problem is that adjustment costs for R&D are likely to be large and this will be reflected in a large value for the lagged dependent variable. Temporary shocks to the price are unlikely to have very large effects and even permanent shocks will take a long time before their full effect is felt. This is compounded by the fact that R&D is characterised by large fixed and sunk costs so the linear form of Eq. (3.4) may be inappropriate. At the least one might consider modelling the decision to participate in R&D separately from the amount of R&D conditional on participation (e.g., Bond et al., 1999).

4. Econometric evidence

Since the preponderance of work has been done on the US we focus first on the results of this work before surveying the smaller number of international studies.

4.1. Studies on the US

Table 2 presents a summary of the results of the many studies of the US R&E tax credit that have been performed since its inception in 1981. In this table we report an attempt to ascertain two standard-

[8] Hall (1993) is the only one of the studies in Tables 2 and 3 to use an Euler equation model for R&D investment demand, but even she is unwilling to trust the estimates and also reports the simple double log specification of the equation as well.

[9] Of course, the fixed effects will also control for many other variables which have been omitted from the specifications such as firm specific knowledge depreciation rates, so they would probably also be useful in the version with the stock of R&D.

Table 2
Empirical studies of the effectiveness of the R&D tax credit — United States

Date of study, author(s)	Collins (1983); Eisner (1983)	Eisner et al. (1983)	Mansfield (1986)	Swenson (1992)	Berger (1993)	Baily and Lawrence (1987; 1992)	Hall (1993)	McCutchen (1993)	Hines (1993)	Nadiri and Mamuneas (1997)
Period of credit	1981:2	1981–1982	1981–1983	1981–1988	1981–1988	1981–1989	1981–1991	1982–1985	1984–1989	1956–1988
Control period	1981:1	1980	Not relevant	1975–1980	1975–1980	1960–1980?	1980	1975–1980	Not relevant	Not relevant
Data source	McGraw-Hill surveys	McGraw-Hill surveys Compustat, IRS ind.	Stratified random survey	Compustat	Compustat	NSF R&D by ind	Compustat	IMS data and 10Ks	Compustat +	
Data type	99 firms	~ 600 firms for R&D 3,4-digit ind for tax	110 firms	263 firms (balanced)	263 firms (balanced)	12 2-digit inds.	800 firms (unbalanced)	20 large drug firms	116 multinationals	15 industries
Methodology	(3) event Compare pre-ERTA est. R&D to post-ERTA spending	(1) dummy R&D equation compared pre- and post-ERTA for R&D above/below base	(4) survey Asked if R&D tax incentive increased	(1) dummy Log R&D demand equation	(1),(3) R&D intensity equation	(1),(2) Log R&D demand eqn with tax price or credit dummy	(2) elasticity Log R&D demand eqn with tax price var.	(1) dummy Research intensity eqn by strategic group with tax credit	(2) elasticity R&D demand eqn with tax price for sec 861-8	Elasticity Cost function approach inc publically financed R&D
Controls		R&D lag 1&2, current & lag sales, CF		Log S, change in LTDebt lag 1&2	Lag R/S, Ind. R/S, Inv/S Ind. Inv/S, CF/S, Tobin's q, GNP	Lag R&D, current and lag output (logs)	Lag R&D, current, lag output (logs)	Past NCEs, divers., sales, % drug sales	Dom. & for. tax price & sales, Ind, firm dummies	Output, public R&D, other factor prices
Estimated elasticity	Insig.	Insig.	0.35?	?	1.0–1.5	0.75 (0.25)	1.0–1.5	0.28–10.0?	1.2–1.6	0.95–1
Estimated benefit-cost	< 1.0	NA	0.30–0.60	NA	1.74	1.3	2	0.29–0.35	1.3–2.00	
Comments	Also used survey evidence, OTA computations	Not a good experiment; too early, insuff. control for TC, poor functional form	Increases get larger as time passes	Credit dummies depend on usability; stratified by tax status	Usability measures problematic	Tax price assumes firm is taxpayer	Response larger in 86–91; IV estimation	Higher response for low CF firms; problem with eq nonhomothetic	Compares firms with and without foreign tax credits — different experiment	Compares optimality of different R&D polices: direct grant vs. R&D

ized results from these quite disparate studies: the price elasticity of R&D (for a typical firm in the sample) and some kind of estimate of the benefit–cost ratio of the credit. In many cases, the data that would allow us to compute these numbers were not really complete in the paper, and we were forced to give nothing, or a rough approximation to the quantity desired. It is apparent from looking at the table that the first wave of estimates (those using data through 1983) differ substantially from the second (those using data through 1988 and later) in two respects. First, the early studies tend to have lower or non-reported tax price elasticities of R&D; only the later study by McCutchen of large pharmaceutical firms is an exception, and the R&D equation in this study appears to be misspecified. Secondly, they are typically not based on the publicly reported 10-K data maintained by Compustat, but on internal U.S. Treasury tax data, surveys and interviews, and, in one case, an early Compustat file. This makes it difficult to ascertain whether the differences in results are because the response to the credit varied over time, or because the type of data used was substantially different.

Unfortunately, the only early study that used a large set of firms from Compustat (Eisner et al., 1983), contains an R&D equation that is not well specified, and does not contain any variable to capture the effect of the tax credit. Thus it is not possible to draw any conclusion about the incentive effect from the regressions published in this report. In order to investigate results using Compustat data in the earlier period, Hall (1995a; b) re-estimated the equations in Table 6 of Hall (1993) for the time period 1981–1982 using ordinary least squares. She found that the estimated tax price elasticity for this earlier period using Compustat data *was* slightly lower than that using Compustat data for the entire 1980s, but still very significant. In either levels or growth rates, it is approximately -0.6 instead of the -0.85 that was obtained for the whole period. If we multiply this elasticity times the weighted average effective credit rates for 1981 and 1982 shown in Table 3 of Hall (1993), we obtain projected increases in R&D spending during these 2 years of 2.1% and 2.3% respectively; consistent with the relatively low increases reported by Eisner and Mansfield using survey data that covered the same period.

As indicated above, later work using US firm-level data all reaches the same conclusion: the tax price elasticity of total R&D spending during the 1980s is on the order of unity, maybe higher. This result was obtained by Berger (1993) using a balanced Compustat panel, Hall (1993) using an unbalanced Compustat panel, Hines (1993) using a balanced Compustat panel of multinationals and a tax price derived from the foreign income allocation rules for R&D rather than the credit, and by Baily and Lawrence (1987; 1992) using aggregate two-digit level industry data. All of these researchers specified an R&D demand equation that contained lagged R&D, current and lagged output, and occasionally other variables such as cash flow. Hall and Hines used instrumental variable techniques to correct for simultaneity in the equation. [10]

Thus there is little doubt about the story that the firm-level publicly reported R&D data tell: the R&D tax credit produces roughly a dollar-for-dollar increase in reported R&D spending on the margin. However, it took some time in the early years of the credit for firms to adjust to its presence, so the elasticity was somewhat lower during that period. Coupled with the weak incentive effects of the early design of the credit, this low short run elasticity implied a weak response of R&D spending in the initial years, causing researchers to interpret it as zero or insignificant. Thus there is no actual contradiction in the evidence.

However, most of the solid evidence we have to date rests upon the response of total R&D spending to changes in the tax price of ''qualified'' R&E. This qualified R&E typically accounts for anywhere from 50% to 73% of total R&D spending. It also rests on rather shaky tax status data, where the effective tax credit rate faced by the firm is inferred using information in the Compustat files on operating losses and taxable income over the relevant years; where aggregate data is used, no attempt has been made to correct for the usability of the credit. There is reason to believe that inferring the qualified R&E spending by multiplying total R&D on the 10-K by a common correction factor (such as 0.6)

[10] Hall uses lags of the endogenous variables in a GMM estimator.

and inferring the tax status by looking at the 10-K numbers is somewhat unreliable. The only study that has used the true (confidential) corporate tax data is that by Altshuler (1989) and unfortunately for our purposes here, it focuses on the weak incentive effect implied by the credit design rather than evaluating the actual R&D induced.

Basing our conclusions on the response of total R&D spending to a tax price inferred from Compustat data may suffer from two quite distinct problems that deserve further investigation: First, as discussed above, the estimates based on public data may be quite noisy, and even misleading. Second, because these estimates are based on the response of reported R&D to the credit itself, they may overestimate the true response of R&D spending to a change in price. This is sometimes called the ‘‘relabelling’’ problem. If a preferential tax treatment for a particular activity is introduced, firms have an incentive to make sure that anything related to that activity is now classified correctly, whereas prior to the preferential treatment, they may have been indifferent between labelling the current expenses associated with R&D as ordinary expenses or R&D expenses. There is some suggestive evidence reported in Eisner et al. (1986) concerning the rate of increase in qualified R&E expenditures between 1980 and 1981, when the credit took effect. Using a fairly small sample of firms surveyed by McGraw-Hill, they were able to estimate that the qualified R&D share grew greatly between 1980 and 1981, less so between 1981 and 1982. This is consistent with firms learning about the tax credit, and shifting expenses around in their accounts to maximize the portion of R&D that is qualified. It is also consistent with the tax credit having the desired incentive effect of shifting spending toward qualified activities, although the speed of adjustment suggests that accounting rather than real changes are responsible for some of the increase.

One way around the relabelling problem is to use a method of estimating the inducement effect that does not rely directly on the responsiveness of R&D to the tax credit. This is the method used in U.S. General Accounting Office (1989) and in the Bernstein (1986) study of the Canadian R&D tax credit. One takes an estimated price elasticity for R&D, estimated using ordinary price variation and not tax price variation, and multiplies this elasticity times the effective marginal credit rate to get a predicted increase in R&D spending due to the credit rate. For example, if the estimated short run price elasticity is -0.13 (as in Bernstein, 1986), and the marginal effective credit rate is 4%, the estimated short run increase in R&D spending from the credit would be 0.5%. With a long-run elasticity of -0.5 (Bernstein and Nadiri, 1989) and a marginal effective credit rate of 10%, the estimated increase would be 5%. In practice, the difficulty with this method has been that most of the elasticity estimates we have are based on a few studies by Bernstein and Nadiri that rely on the time series variation of an R&D price deflator that evolves as a fairly smooth trend and so is correlated with many other changes in the economy.[11] In addition, they are based on either industry data from the 1950s and 1960s or a very small sample of manufacturing firms, so they may not generalize that easily.

It is unlikely that the R&D demand elasticity with respect to price is constant over very different time periods or countries, so it would be desirable to have more up-to-date estimates in order to use this method. Obviously, one can never be sure that firms will actually respond to a tax incentive in the way implied by the price elasticity and measured credit rate, but it would be useful to have this method available as a check on the more direct approach using tax prices.

4.2. Non-US studies

Few countries have performed as many studies of their incremental R&D tax credit programs as the US. There are several reasons for this: (1) Most of these schemes have been in place for a shorter time period. (2) They have relied on the US evaluations for evidence of effectiveness. (3) Internal government studies may have been done, but these are hard to come by if you are not connected with researchers within the government in question. The only studies we have been able to find are displayed in Table 3. They cover Australia, Canada, France, Japan, and Sweden.

[11] See also Goldberg (1979), Nadiri (1980), Cardani and Mohnen (1984), Mohnen et al. (1990).

Table 3
Studies of the of the R&D tax credit — other countries [see text for a more complete of methodologies (1)–(4)]

Country	Canada	Canada	Sweden	Canada	Japan	Australia	Canada	G7 and Australia	France	Canada
Author(s), date of study	McFetridge and Warda (1983)	Mansfield and Switzer (1985a; b)	Mansfield (1986)	Bernstein (1986)	Goto and Wakasugi (1988)	Australian Bureau of Industry Economics (1993)	Bernstein (1998)	Bloom et al. (1998)	Asmussen and Berriot (1993)	Dagenais et al. (1997)
Period of credit	1962–1982	1980–1983	1981–1983	1981–1988	1980	1984–1994	1964–1992	1979–1994	1985–1989	1975–1992
Control period	NA	Not relevant	Not relevant	1975–1980		Non-users				
Data source	Statistics Canada	Stratified survey interview	Stratified random survey	Prior estimates		ABS R&D survey IR&D board	Canadian manufacturing	Manufacturing sector (panel estimates)	DGI, and MRT data	Canadian Compustat Statcan deflators
Data type	Aggregate	55 firms (30% of R)	40 firms	Firms?		> 1000 firms	Sector	9 countries	339 firms	434 firms
Methodology	(2) Elasticity, use elasticity of 0.6 and tax price of R&D	(4) Survey, asked if R& D tax incentive increased spending	(4) Survey, asked if R& D tax incentive increased spending	(2) Elasticity multiply prior elasticity estimate times credit rate		(1), (4) Log R&D demand eqn with credit dummy control/no control	Elasticity cost function approach	Elasticity R &D demand eqn with tax-adjusted user cost	(1) Demand R&D demand eqn with log(credit)*, Indicator for ceiling	(1) Demand, log R&D stock eqn with og(credit)*, sample sel. model

Controls	NA	No control years, unclear if these are total increases from tax credit	NA			Lag R&D, log size growth, tax loss dummy, gov support dummy	Output other factor prices	Lagged R&D, output country and time dummies	Logs of gov subsidy, size, size sq, concentration,	Log sales, log capital, ind. R stock, lag R stock fixed effects
Estimated Elasticity	0.6	0.04–0.18	small	0.13		−1.0	0.14 in short-run 0.30 in long-run	0.16 in short-run 1.1 in long-run	0.26 (.08)	0.40 (.25)
Estimated Benefit-cost	0.60	0.38–0.67	0.3 to 0.4	0.83–1.73		0.6–1.0			?	0.98 (LR)
Comments	Elasticity comes from Nadiri (1980) ''tentative''	Elasticity estimated from McF& Warda tax cr. of 20% and obs. R increase	Increases get larger as time passes.	Larger figure includes outout effects	Increased R&D by 1%	Elasticity is comb. of survey evidence and control group analysis		Find effect of tax credits on relocation decision	Estimated elasticity is credit elasticity divided by elasticity of tax price wrt credit	Includes a selection eqn for doing R&D; elasticity derived from stock est. C-B includes output

There have been several studies of Canadian data. Dagenais et al. (1997) analyse Canadian firms using the substantial variation in the R&D tax credit to construct a measure of the user cost. They estimate a generalised Tobit model for the R&D stock which allows the tax price to affect the amount of R&D performed as well as whether firms conduct R&D at all. They find a weakly significant effect on the former with a long-run effect almost 20 times the short-run effect. Through a simulation exercise they find that a 1% increase in the federal tax credit generates an average of US$0.98 additional R&D expenditure per dollar of tax revenues foregone.

One of the most comprehensive and carefully done of these studies is that by the Australian Bureau of Industry Economics. It is noteworthy that the conclusions reached with respect to the tax price elasticity and benefit–cost ratio are similar to those in the recent US studies. The methodology used compares the R&D growth rates for firms able and unable to use the tax credit for tax reasons. This has the obvious disadvantage that assignment to a control group is endogenous, and that the full marginal variation of the tax credit across firms is not used, only a dummy variable. In general, the survey evidence that asks firms by how much they increased their R&D due to the tax credit is consistent with the econometric evidence.

The French study by Asmussen and Berriot (1993) encountered some data difficulties having to do with matching firms from the enterprise surveys, R&D surveys, and the tax records, so the sample is somewhat smaller than expected, and may be subject to selection bias. The specification they used for the R&D demand equation includes the magnitude of the credit claimed as an indication of the cost reduction due to the credit. If all firms faced the same effective credit rate on the margin, it is easy to compute the tax price elasticity from the coefficient of this variable. Unfortunately, this is typically not true in France, so that this equation is not ideal for the purpose of estimating the tax price elasticity. Even so, Asmussen and Berriot obtain a plausible estimate of 0.26 (0.08), which is consistent with other evidence using similar French data and a true tax price.

Few studies have attempted to systematically compare the effectiveness of various R&D tax incentives across countries, partly because of the formidable obstacles to understanding the details of each system. McFetridge and Warda (1983) and Warda (1994) have constructed estimates of the cost of R&D for large numbers of major R&D-doing countries. Like the Bloom 1998, 2000 study discussed in Section 2 they found that Japan, Germany, Italy, Sweden, and the UK had the highest tax cost of R&D projects and the US, France, Korea, Australia, and Canada the lowest. Bloom 1998, 2000 use the user-cost calculated over eight countries in Section 2 to analyse the effect on R&D. Like the micro studies they also find a long-run elasticity of about unity but a very low short run elasticity (0.16). More interestingly they identify significant effects of the foreign user cost of capital which they interpret to mean that changes in R&D tax credits can stimulate firms into relocating their R&D across borders. This raises a new dimension in the debate over the efficacy of tax credits. If some of the estimated increase comes from multinationals relocating their R&D laboratories it raises the question of tax competition over ''footloose'' R&D.

The central conclusion at present from studies in other countries is not different from those using US data: the response to an R&D tax credit tends to be fairly small at first, but increases over time. The effect of incremental schemes with a moving average base (France, Japan) is the approximately the same as in the US: they greatly reduce the incentive effect of the credit.

5. Conclusions

In this paper we have considered the tax treatment of R&D and its effect on firm's decisions. Because R&D is expensed it is tax privileged compared to fixed investment. There are also a host of special tax breaks, such as the US R&E credit that further subsidise R&D activities. These have varied extensively over time and across countries to a much greater extent than physical capital. Our sense is that the tax treatment of R&D is becoming more lenient and it is likely that countries will increasingly turn to the tax system and away from direct grants.

One feature of the existing schemes is that they imply very heterogenous prices facing firms. This variation is a useful source of identification of the effect of price changes on quantity demanded, although there are still relatively few studies that have used this. Taken as a whole there is substantial evidence that tax has an effect of R&D performed, the most compelling evidence coming from the quasi-experimental approach of calculating a user cost of R&D and estimating an explicit econometric model. A tax price elasticity of around unity is still a good ballpark figure, although there is a good deal of variation around this from different studies as one would expect.

Looking ahead there are several ways in which the literature could grow. First, expanding beyond the US to other countries is a trend which clearly needs to be encouraged. International firm level datasets are becoming more widely available and we would emphasis to policy makers the imperative of having more open, objective, statistical evaluations of their policies. Secondly, there has been little attempt to use the variation in tax prices as an instrument for R&D in examining other variables of interest. For example we are interested in the question of the productivity effect of R&D and whether the tax credit could be used as a quasi-experiment to get better calculations of the return to R&D investments. Finally, the issue political economy cuts through many of the issues here. Why and when do governments introduce tax breaks? Are they reacting to policies in other countries as the theory of tax competition suggests they will? Understanding the process by which different policies are conceived and come to life is as important as evaluating their effects once they are born and grown up.

Acknowledgements

This paper draws on previous work by the authors (especially Hall, 1995a,b and Bloom et al., 1998, 2000) and their colleagues. Special thanks to Lucy Chennells, Nick Bloom and Rachel Griffith. The second author thanks funding from the ESRC Centre for Microeconomic Analysis of Fiscal Policy at the Institute for Fiscal Studies.

Appendix A. Measuring the user cost of R&D

The user cost of R&D is calculated using the standard approach of Hall and Jorgenson (1967) and King and Fullerton (1984) and that was extended to the international setting in OECD (1991) and Devereux and Pearson (1995). The aim of this approach is to derive the pre-tax real rate of return on the marginal investment project that is required to earn a minimum rate of return after tax. This will be a function of the general tax system, economic variables and the treatment of R&D expenditure in particular.

We consider a profit maximising firm which increases its R&D stock by one unit in period one, then disposes of that unit in the second period. The tax system affects the cost of making this investment in two ways. First, the revenue earned from the investment is taxed at rate τ. Second, the cost of the investment to the firm is reduced by depreciation allowances and tax credits.

Assuming that depreciation allowances are given on a declining balance basis at rate ϕ_t and begin in the first period the value of the depreciation allowance will be $\tau_t \phi_t$ in period one, and in subsequent periods the value falls by $(1-\phi_t)$. [12] Denote the net present value of the stream of these depreciation allowances A_t^d,

$$A_t^d = \tau_i \phi_t + \frac{\tau_i \phi_t (1-\phi_t)}{(1+r_t)} + \frac{\tau_i \phi_t (1-\phi_t)^2}{(1+r_t)} + \cdots$$

$$= \frac{\tau_t \phi_t (1+r_t)}{(\phi_t + r_t)}$$

where r_t is the discount rate and the asset and country subscripts have been omitted for simplicity.

Similarly we can calculate the net present value of the tax credit, A_t^c, which will depend on the type of tax credit available on R&D expenditure. The main features that affect the value of a tax credit are whether the credit applies to total or incremental

[12] In practice depreciation allowances generally begin in the second period, or are given at half the rate in the first period. This is taken account of in the empirical application. Depreciation allowances may also be given on a straight line basis, in which case the expression for A_t^d is slightly different.

expenditure, how the base level of expenditure is defined in the incremental case and whether the credit is capped on a firm by firm basis.

Under the assumption of perfect foresight and no tax exhaustion the net present value of an incremental tax credit with a base that is defined as the k-period moving average is

$$A_t^c = \tau_t^c \left(B_t - \frac{1}{k} \sum_{k}^{i=1} (1+r_t)^{-i} B_{t+i} \right) \tag{A.1}$$

where τ_t^c is the statutory credit rate, B_{t+i} is an indicator which takes the value 1 if R&D expenditure is above its incremental R&D base in period t and zero otherwise. If the credit has an absolute firm level cap, as in France, then A_t^c is assumed to be as above for firms below the credit caps and zero for those above the cap.

The depreciation allowances and tax credits vary across types of asset, countries and time. We consider investment in the manufacturing sector into three types of asset for use in R&D — current expenditure, buildings, and plant and machinery. An important assumption in the modelling strategy used here is that current expenditure on R&D is treated as an investment — that is its full value is not realised immediately. We also assume that domestic investment is financed by retained earnings.

In an individual country, the user cost of a domestic investment in R&D for each asset (indexed by j) is given by

$$\rho_{jt} = \frac{1-\left(A_{jt}^d + A_{jt}^c\right)}{1-\tau_t}\left(r_t + \delta_j\right) \tag{A.2}$$

where δ_j is the economic depreciation rate of the asset. The economic depreciation rates used are 30% for current expenditure on R&D, 3.61% for buildings and 12.64% for plant and machinery. The domestic user cost of R&D for an individual country is then given by

$$\rho_t = \sum_{j=1}^{3} w_j \rho_{jt}^d \tag{A.3}$$

where w_j are weights equal to 0.90 for current expenditure, 0.064 for plant and machinery and 0.036 for buildings (see OECD (1991)). The tax component of the user cost of R&D is constructed using a constant real interest rate across countries and over time (10%).

$$\rho_{jt}^{\tau} = \frac{1-\left(A_{jt}^d + A_{jt}^c\right)}{1-\tau_t} \tag{A.4}$$

References

Altshuler, R., 1989. A dynamic analysis of the research. National Tax Journal XLI, 453–466.

Asmussen, E., Berriot, C., 1993. Le credit d-impot recherche, cout et effet incitatif. Ministere de l'Economie et des Finances, Paris, France (Avril 1993). Photocopied.

Australian Bureau of Industry Economics, 1993. R&D, Innovation and Competitiveness: An Evaluation of the R&D Tax Concession. Australian Government Publishing Service, Canberra.

Baily, M.N., Lawrence, R.Z., 1987. Tax Policies for Innovation and Competitiveness. Study commissioned by the Council on Research and Technology, Washington, DC, (April 1987). Photocopied.

Baily, M.N., Lawrence, R.Z., 1992. Tax Incentives for R&D: What Do the Data Tell Us? Study commissioned by the Council on Research and Technology, Washington, DC, (January 1992). Photocopied.

Bell, J., 1995. The Australian 150% tax concession for R&D. Presentation of the Australian Delegation to the OECD Ad Hoc Meeting on Fiscal Measures to Promote R&D and Innovation, Paris, France.

Berger, P., 1993. Explicit and implicit effects of the R&D tax credit. Journal of Accounting Research 31, 131–171.

Bernstein, J.I., 1986. The effect of direct and indirect tax incentives on Canadian industrial R&D expenditures. Canadian Public Policy XII, 438–448.

Bernstein, J.I., Nadiri, M.I., 1989. Rates of return on physical and R&D capital and structure of the production process: cross-section and time series evidence. In: Raj, B. (Ed.), Advances in Econometrics and Modelling. Kluwer Academic Publishers, Amsterdam, pp. 170–187.

Bloom, N., Griffith, R., Van Reenen, J., 1998. Do R&D tax credits work? Evidence from an international panel of countries 1979–1994, Institute for Fiscal Studies Working Paper W99/8.

Bloom, N., Chennells, L., Griffith, R., Van Reenen, J., 2000. In: Lawton-Smith, H. (Ed.), The Economics of Regulation of High Technology Industries. Oxford Univ. Press, Oxford.

Bond, S., Van Reenen, J., 1998. Econometric models of factor demand. Mimeo, IFS.

Bond, S., Harhoff, S., Van Reenen, J., 1999. Investment, R&D and financial constraints in Britain and Germany. Institute for Fiscal Studies Working Paper Series W99/8.

Cohen, L.R., Noll, R.G., 1991. The Technology Pork Barrel. Brookings Institution, Washington, DC.

Collins, E., 1983. An early assessment of three R&D tax incentives provided by the Economic Recovery Tax Act of 1981.

Vol. PRAReport 83-7. National Science Foundation, Washington, DC.

Dagenais, M., Mohnen, P., Thierrien, P., 1997. Do Canadian Firms Respond to Fiscal Incentives to Research and Development? Tilburg University mimeo.

Eisner, R., Steven, H.A., Sullivan, M.A., 1983. Tax incentives and R&D expenditures. In: Proceedings of the Conference on Quantitative Studies of Research and Development in Industry, edited by Ecole Nationale de la Statistique et de l'Administration Economique and National Bureau of Economic Research, Vol. 2. CNRS, Paris, France, 1983, pp. 375–466.

Eisner, R., Albert, S.H., Sullivan, M.A., 1986. The new incremental tax credit for R&D: incentive or disincentive. National Tax Journal XXXVII, 171–183.

Goto, A., Wakasugi R., 1988. Technology Policy. In: Komiya, R., Okuno, M., Suzumura, K. (Eds.), Industrial Policy of Japan. Academic Press, Tokyo, 1988.

Griffith, R., Sandler, D., Van Reenen, J., 1995. Tax incentives for R&D. Fiscal Studies 16, 21–44.

Hall, B.H., 1993. R&D tax policy during the eighties: success or failure? Tax Policy and the Economy 7, 1–36.

Hall, B.H., 1995. Fiscal policy towards R&D in the United States: recent experience. Presentation to the OECD Working Group on Fiscal Measures to Promote R&D, Paris, France, January 19, 1995.

Hall, B.H., 1995. Effectiveness of research and experimentation tax credits: critical literature review and research design. Report to Office of Technology Assessment, Congress of the United States.

Hall, R., Jorgenson, D., 1967. Tax policy and investment behaviour. American Economic Review 57, 391–414.

Harhoff, D., 1994. The tax treatment of R&D expenditure. ZEW and University of Mannheim, Research Report No. 94-02, Mannheim, Germany, (1994). Photocopied.

Hines, J.R., Jr., 1993. On the sensitivity of R&D to delicate tax changes: the behavior of U.S. multinationals in the 1980s. In: Giovannini, A., Hubbard, R.G., Slemrod, J. (Eds.), Studies in International Taxation, Ill. University of Chicago Press, Chicago, pp. 149–94.

Hiramatsu, H., 1995. Japanese fiscal measures to promote R&D. Presentation of the Japanese Delegation to the OECD Ad Hoc Meeting on Fiscal Measures to Promote R&D and Innovation, Paris, France, January 19.

King, M.A., Fullerton, D. (Eds.), 1984. The taxation of income from capital: a comparative study of the United States, the United Kingdom, Sweden, and West Germany. University of Chicago Press.

Klette, T., Møen, J., Griliches, Z., 2000. Do subsidies to commercial R&D reduce market failures? Microeconomic evaluation studies. Research Policy 29 2000, 473–497.

KPMG, 1995. Tax Treatment of Research and Development Expenses. KPMG International Tax Centre, Amsterdam.

Leyden, D.P., Link, A.N., 1993. Tax policies affecting R&D: an international comparison. Technovation 13, 17–25.

Mansfield, E., 1986. The R&D tax credit and other technology policy issues. AEA Papers and Proceedings 76, 190–194.

Mansfield, E., Switzer, L., 1985a. The effects of R&D tax credits and allowances in Canada. Research Policy 14, 97–107.

Mansfield, E., Switzer, L., 1985b. How effective are Canada's direct tax incentives for R&D?. Canadian Public Policy 11, 241–246.

McCutchen, W.M. Jr., 1993. Estimating the impact of the R&D tax credit on strategic groups in the pharmaceutical industry. Research Policy 22, 337–351.

McFetridge, D.G., Warda, J.P. 1983. Canadian R&D incentives: their adequacy and impact. Vol. Canadian Tax Paper No. 70, Canadian Tax Foundation, Toronto.

Nadiri, M., 1980. Contributions and determinants of research and development expenditures in the US manufacturing industries. In: von Furstenburg, G. (Ed.), Capital, Efficiency and Growth. Ballinger, Cambridge.

OECD, 1984. Science and Technology Policy: Review and Outlook. OECD/OCDE, Paris, France.

OECD, 1980. The Measurement of Scientific and Technical Activities. General Guidelines for Statistical Summaries of Research and Experimental Development, OECD/OCDE, Paris, France.

OECD, 1991. Taxing Profits in a Global Economy: Domestic and International Issues, Paris.

Seyvet, J., 1995. Le Credit d'Impot Recherche (CIR) en France. Ministere de l'Enseignement Superieur et de la Recherche. Presentation to the OECD Working Group on Fiscal Measures to Promote R&D, Paris, France, January 19, 1995.

Shah, A., 1994. The economics of research and development: how research and development affects production and markets and is affected by tax incentives. Working Paper 1325, World Bank, Policy Research Institute.

Stoffregen, P.A., 1995. Giving credit where credit is due: a brief history of the administration of the R&D tax credit. Tax Notes 1995, 16 January 1995, pp. 403–16.

Swenson, C.W., 1992. Some tests of the incentive effects of the research and experimentation tax credit. Journal of Public Economics 49, 203–218.

U.S. General Accounting Office, 1989. The research tax credit has stimulated some additional research spending. Vol. GAO/GGD-89-114, U.S. General Accounting Office, Washington, DC.

Warda, J., 1994. Canadian R&D tax treatment: an international comparison. Vol. Report No. 125-94. The Conference Board of Canada, Ottawa, Ontario.