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ABSTRACT Differentiating internal equity from debt finance, this study examines the generosity of R&D-specific tax incentives in OECD countries based on an NPV model. The corporate tax system generally favours debt finance and some previous findings on the possible preponderance of internal equity for financing R&D investment cannot be explained in relation to R&D-specific tax concessions. The OECD comparison demonstrates that R&D tax allowances adopted in the Czech Republic, Belgium, the UK, Denmark, Hungary, Austria and Australia generated the most substantial tax savings in 2006. Combined with such incentives, the after-tax NPV increases with the corporate tax rate, suggesting stronger investment stimulation through a tax-rate-*increase*-cum-base-broadening policy.

KEY WORDS: Corporate tax incentives, R&D investment, financial structure, net present value, OECD countries
JEL CLASSIFICATIONS: H25, H32, O30

1. Introduction

It is generally acknowledged that economic growth is driven by the accumulation of knowledge-based factors of production such as human capital, R&D and innovation. Moreover, such knowledge-based production factors determine a nation's long-term competitiveness in a global world (Grossman & Helpman, 1991). In this context, the so-called endogenous growth theory argues that technological advancement is particularly stimulated by R&D activities of profit-maximizing firms (Romer, 1994). R&D enters the production process as a factor of production

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and is used in conjunction with other inputs. On the other hand, as with any investment decision, R&D is not undertaken unless there is an opportunity for profit.

In many OECD countries specific tax incentives aimed at stimulating firms' R&D investment activities have traditionally been kept (and even expanded) as an important measure of technology and innovation policy, although the majority of developed countries have carried out a series of 'tax-rate-cut-cum-base-broadening' corporate tax reforms in last two decades.[1] This fact suggests that there has also been a sort of tax competition among the OECD countries regarding R&D promotion. In addition, the finding that social rates of return to R&D are substantially above private rates of return provides one of the main justifications for such government subsidies to R&D. Many believe that the lower private rates of return than the social rates cause the under-investment in R&D (Griffith, 2000). Furthermore, a tax-base subsidy appears to be the market-oriented response, since it leaves the choice of how to conduct and pursue the R&D programs in the hands of the private sector (Hall & van Reenen, 2000).

Another attractive feature of these instruments is that tax incentives can be more predictable and accessible for businesses than direct subsidies. A possible drawback of fiscal instruments is that firms will not concentrate on projects with a high social rate of return. An additional shortcoming was believed to be '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 [used to be] the conventional wisdom […]' (Hall & van Reenen, 2000, p. 449). Such theoretical considerations for the preferential tax treatment of R&D investment are supported by a large number of previous empirical investigations, which suggest its positive impact on firms' R&D spending in many OECD countries (see Table 1).

Compared with the case with usual fixed capital investment, financing constraints seem to apply more seriously to R&D investments (Bagella *et al.*, 2001; Ughetto, 2008). Apart from the capital market imperfection leading to information asymmetry between lenders and borrowers when financing R&D investments (Hubbard, 1998), the limited availability of providing collateral to secure firm's borrowing and the relatively high risk as well as the complex evaluation related to the future success of innovation activities make equity finance more attractive than debt finance. In particular, internally generated cash flow popularly applied for financing R&D investments in advanced economies has several advantages over debt including: (a) no collateral requirements, (b) avoidance of adverse selection problems, and (c) the limited scope of financial distress (Carpenter & Petersen, 2002; Brown *et al.*, 2007). On the other hand, a strong reliance on internal equity can hinder the realisation of profitable and socially-desirable R&D opportunities of young and fast-growing innovative firms that require a higher sum of financial means than their internal cash flow obtained from existing profits. In addition, a smooth R&D investment path over time tends to be desirable. Yet the

[1]The lower corporate tax rate tends to increase the incentive to invest, while the lower allowance is likely to decrease it. Therefore, the combined effect appears to depend on the details of each tax-rate-cut-cum-base-broadening reform in the individual OECD countries (Devereux *et al.*, 2002).

Table 1. Positive effects of R&D-specific tax incentives revealed by selected empirical investigations

Empirical studies	Major findings
Bernstein (1986)	The investigated period is 1975–1984, in which current and capital R&D was deductible in Canada, a credit received for all current and capital R&D (ranging from 10–25%), and an allowance given for incremental increases. If there is no growth in the Canadian economy, the R&D credits and allowances generate $0.80 additional R&D expenditure per $1 tax foregone. When the effect of the tax credit is included in the return by virtue of expanded output, the R&D generated exceeds the tax foregone.
Cordes (1989)	For the survey period 1981–1985 there would be $0.35-$0.93 additional company R&D spending per $1 tax foregone if the US tax credit was made permanent.
Berger (1993)	The study analyses the US tax credit system during the 1980s. It estimates $1.74 extra spending on R&D for every $1 tax foregone.
McCutcheon (1993)	This research examines the pharmaceutical industry in relation to the US Tax Reform Act of 1986. The tax credit causes an increase in R&D expenditures, increases competitive R&D spending in firms in the same industry; a 1.6% increase of R&D investment is attributable to the credit.
Hall and van Reenen (2000)	This study describes the effect of the tax system in OECD countries on the user cost of R&D and concludes (with many disclaimers) that $1 of tax credit for R&D stimulates an extra $1 of R&D.
Bloom *et al*. (2002)	For the period 1979–1994 this econometric analysis of data on tax changes and R&D spending involves Australia, Canada, France, Germany, Italy, Japan, Spain, United Kingdom and United States. A 10% fall in the cost of R&D (such as through tax breaks and/or credits) stimulates just over a 1% rise in the level of R&D in the short run, and just under a 10% rise in R&D in the long run.
Guellec and van Pottelsberghe (2003)	For the period 1981–1996 direct government funding made in 17 OECD countries results in $1.70 of research spending on average for every $1 financed and that tax incentives have a positive but short-lived effect.
Mulkay and Mairesse (2004)	This study evaluates the effect of the French incremental tax credit system on R&D expenditure for the period 1980–1997. If its statutory rate is raised by 10%, the optimal R&D capital is anticipated to grow by 4.6%. Consequently, its effect on R&D expenditure is three times larger than its budgetary cost.

Source: Sawyer (2005).

profit volatility caused by business cycle fluctuation may create an uncertainty in yielding necessary internal financial means required for R&D investments (Ughetto, 2008).

As a large number of studies have already shown, the tax system is acknowledged as:

> neutral towards corporate financing decisions if a given pre-tax flow of corporate profits produces the same after-tax income in the hand of the ultimate investors, whether the return of investors takes the form of interest payments, of dividends, or of capital gains on shares. This requires that the combined corporate and personal tax burden on a unit of distributed profits be equal to the combined tax burden on retained profits, and that the total burden on distribution or retentions in turn be equal to the effective tax rate on a unit of corporate interest payments. OECD corporate tax systems are generally not neutral towards corporate financing decisions, in that they tend to favour debt finance. This is because corporate interest payments are deductible from the corporate tax base and because effective tax rates on interest income are often low. (Messere *et al.*, 2003, p. 122)

Under the clear distinction between internal equity and debt finance, this study examines the generosity of various types of corporate tax incentives implemented in OECD countries to promote firms' R&D investments on the basis of a net present value (NPV) model – a popular 'forward-looking' dynamic investment decision model.[2] In other words, this study deals with a narrow scope of aspects related to corporate profit taxation and argues that discrete R&D investment decisions of profit maximising firms are dependent on the post-tax NPV. As with many other previous research outcomes this study also confirms that the corporate tax system favours debt finance, since by a given tax depreciation scheme the absolute amount of after-tax NPV with debt finance is larger than that with internal equity finance. However, the explanation for the reasons is not only limited to the conventional, sole argument that corporate interest payments are deductible from the tax base, which in turn create extra tax savings. With debt finance, annual gross profits are also reduced by the amount of interest payments, from which the entire corporate tax burden is subtracted to calculate the post-tax profits.[3] Moreover, other than the case of financing investment cost by firms' internal equity, the present value of debt-financed investment cost which is taken into account when computing the after-tax NPV becomes lower, since discounting (with the real interest rate) takes place for the repayment of the entire debt sum at the end of the given maturity years. The compound effect of all these features determines the superiority of debt finance. Yet, the preponderance of internal equity finance for R&D investment appears to be hardly explained in relation to the corporate tax incentive system, because the additional promotion effects (also expressed in terms of the post-tax NPV) of generous R&D-specific tax incentives

[2]The superior features of NPV over the calculation of effective (marginal and average) corporate tax rates (King & Fullerton, 1984; Devereux & Griffith, 2003; Sørensen, 2004; Devereux, 2004) include, for example, that (i) the development of gross return generated by an investment can be more adequately considered, (ii) the true economic depreciation rate is not assumed but endogenously derived from the trend of gross return, and (iii) firms most widely apply this method in practice, especially when carrying out the so-called feasibility study for checking overall profitability of investment projects (see also Nam & Radulescu, 2007).

[3]Consequently this leads to the reduction of the after-tax NPV.

over the normal depreciation rules (allowed for usual fixed capital investments) in the individual OECD countries remain the same, regardless of the different types of financial coverage of investment costs. Furthermore, with tax allowances and tax credits leading to the greatest R&D investment promotion effects in OECD countries, the after-tax NPV ceteris paribus increases with the corporate tax rate. This fact, in turn, suggests the possibility of stronger R&D investment promotion by adopting a sort of 'tax-rate-*increase*-cum-base-broadening' policy, a rather different tax policy option from the dominating tax-rate-cut-cum-base-broadening idea widely implemented in OECD countries.

The structure of this paper is as follows. Section 2 explains the current R&D-oriented tax incentive systems in the OECD countries. After revisiting the Modigliani-Miller theorem of capital structure irrelevance, the third section technically describes the major nature of the present value model applied for the calculation of R&D investment promotion effects of the aforementioned tax policy measures. Section 4 illustrates the empirical results based on the calculated after-tax NPV under the plausible parameter assumptions and compares the international competitive position of individual countries led by the different R&D-promoting tax schemes. The final section summarises the major findings of the study and concludes.

2. Current Tax Treatment of R&D Investment in OECD Countries

The statutory corporate tax rate is certainly important in determining the overall profit tax burden. However, this tax rate does not, in itself, establish the ultimate tax burden on a firms' R&D investment activity. Equally crucial are the effects of depreciation and other investment promotion schemes that determine the tax base (Sørensen, 2004). In the practice of corporate tax policy, different tax depreciation rules are employed that do not typically ensure the true economic depreciation (Samuelson, 1964). Furthermore, their generosity has been extended to stimulate R&D investment activity of a firm. Similarly, the R&D tax allowances provide an additional deduction from taxable income of a firm, which indirectly lowers the amount of tax owed. In addition, the R&D tax credits are more widely applied in OECD countries that allow a deduction from the tax a firm must pay to tax authorities (Warda, 2006). Yet there are also countries that do not have any of the three types of R&D-specific tax incentive schemes, as was the case in Germany, Poland and Sweden in 2006 (Table 2).[4]

Apart from the different statutory corporate tax rates that vary from 12.5% (Ireland) to 35% (Spain) in 2006, Table 2 also delivers an overview of the R&D-specific depreciation rules applied in selected OECD countries, when the normal tax life for equipment is assumed to be 10 years. For example, free depreciation (*FD*) was most widely applied in OECD countries including Canada, France,

[4]In addition, the Slovak corporate tax system has not recently provided any specific preferential tax-treatment for R&D investment at all (see Mennel, 2007). According to OECD (2007), Sweden and Germany have traditionally been the OECD countries with the highest GDP share of business expenditures in R&D (BERD), while Poland and Slovakia are positioned at the bottom of the ranking in the period 2001–2005.

Table 2. Tax incentive measures for R&D equipment investment in selected OECD countries when normal tax life = 10 years (2006)

Country	Statutory corporate tax rate (%)	Tax depreciation rule for investment in general	Specific tax depreciation rules for R&D investment	R&D allowances from taxable income (in % of investment expenditure)		R&D tax credits (in % of investment expenditure)	
				Current volume	Increment	Current volume	Increment
Australia	25	20% GDD		125	175		
Austria	25	10% SLD		125	135	8	
Belgium	34	20% GDD	33.3% SLD	113.5			
Canada	22.1	30% GDD	FD			20	
Czech Rep.	24	10% SLD		200			
Denmark	28	25% GDD		150			
France	33.3	22.5% GDD	FD			5	45
Germany	25	10% SLD					
Hungary	20.5	10% SLD	20% SLD	200–400			
Ireland	12.5	20% SLD	FD				20
Japan	30	20% GDD				10–15	
Luxembourg	22.9	10% SLD	40% GDD				
Netherlands	25	10% SLD	FD			14	
Poland	19	10% SLD					
Portugal	25	25% GDD	40% GDD			20	50
Spain	35	10% SLD				20	50
Sweden	28	30% GDD					
UK	30	25% GDD	FD	125			
USA	35	20% GDD					20

Note: SLD = straight-line depreciation; GDD = geometric-degressive depreciation; FD = free depreciation.
Sources: Warda (2006); Mennel (2007).

Ireland, the Netherlands and the UK (see the fourth column of Table 2). The third column of Table 2 suggests that in many countries (e.g. Australia, Belgium, Canada, Denmark, France, Ireland, Japan, Portugal, Sweden, the UK and the US) even a firm's normal investment activity was stimulated mostly by generous geometric-degressive depreciation (*GDD*) in the same year. On the basis of such 'normal' depreciation rules (in the third column) additional incentive effects of R&D-specific depreciation rules (and also tax allowances and tax credits) can be identified.

In 2006, R&D tax allowances were offered in some OECD countries, including Australia, Austria, Belgium, the Czech Republic, Denmark, Hungary and the UK. Most are volume-based, while Australia and Austria allowed a combination of both level-based and incremental allowances (see also Table 2). For a firm's R&D investment made in collaboration with public research institutions, a special allowance of 400% (of investment spending) was possible in Hungary.

Several selected OECD countries allowed R&D tax credits in 2006. As also shown in Table 2, a larger share of countries (e.g. Austria, Canada, Japan and the Netherlands) offered this type of tax incentive based on the total volume of the firm's R&D investment. On the other hand, purely incremental tax credits were popular in Ireland and the United States, of which amounts are determined as a percentage share of a firm's R&D spending increase over some base period. France, Portugal and Spain had a mixed system of volume-based and incremental tax credits.[5] According to Warda (2006), there has been a shift away from incremental towards volume-based tax credits over time. None of the east European OECD members had such an R&D promotion measure.

3. Net Present Value Model

3.1 *Modigliani–Miller Theorem of Capital Structure Revisited*

According to Modigliani and Miller (1958), the market value of a firm does not depend upon its capital structure, when conditions are satisfied, such as perfect markets (i.e. no taxes or transaction costs); the cash flows that are independent of financial structure; and riskless debt such that firms and individuals can borrow and lend at a risk free interest rate.

When (i) an investment costing C generates an infinite stream of future gross return; (ii) the return exponentially declines at rate α ($0 < \alpha < 1$); and (iii) all prices are constant over time, an internal equity-financed investment project is on the margin of acceptance at the year of investment (i.e. $NPV_0^E = PV_0^E - C = 0$), if

$$C = PV_0^{\mathrm{E}} = \int_0^{\infty} A_0 e^{-(\alpha+r)u} \mathrm{d}u = \frac{A_0}{\alpha + r} \tag{1}$$

where A_0 = gross return at year $u = 0$ ($A_0 > 0$); r = real interest rate ($0 < r < 1$); and PV_0^E = present value of asset at year 0 with equity finance. Under the assumption of perfect competitive market structure mentioned above, only one real

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[5]South Korea also offers both a volume-based and an incremental tax credit, but these two credits are mutually exclusive, which means that a firm can claim only one of these credits (Warda, 2006).

interest rate exists in the financial market. Additionally, α is the same as Samuleson's true economic depreciation rate (Samuelson, 1964; Atkinson & Stiglitz, 1980; Nam & Radulescu, 2007).

In the case of financing the investment cost C through debt, a firm pays the creditor not only the annual interest of rC for s years but also the entire amount of C to the creditor at the end of this maturity year. Therefore, present value of total cost at year 0 (C_0^F) can be expressed:

$$C_0^F = \int_0^s rCe^{-ru}du + Ce^{-rs} = (1 - e^{-rs})C + Ce^{-rs} = C \tag{2}$$

Since the annual interest payment reduces the future gross return for s years, the following steady-state condition applies for the debt-financed investment in the absence of tax,

$$C_0^F = Ce^{-rs} + \int_0^s rCe^{-ru}\,du = PV_0^F = \int_0^\infty A_0 e^{-(\alpha+r)u}\,du \tag{3}$$

where PV_0^F = present value of asset at year 0 with debt finance. With debt finance, $NPV_0^F = 0$, when $PV_0^F = C_0^F$.

Rearranging equations (2) and (3) leads to

$$C_0^F = Ce^{-rs} + (1 - e^{-rs})C = C = PV_0^F = \frac{A_0}{\alpha + r} = PV_0^E \tag{4}$$

Hence, the traditional Modigliani-Miller theorem applies (see also Nam & Radulescu, 2005).

3.2 *Effects of Tax Incentives for R&D Investment*

In tax policy practice, various tax depreciation measures are employed that do not ensure true economic depreciation. Moreover, their generosity has been extended to stimulate private investment (Atkinson & Stiglitz, 1980; Sinn, 1987; Nam & Radulescu, 2005). For example, in the case of introducing the corporate tax rate t in combination with straight-line depreciation (*SLD*) over a tax-life of Γ years, the 'after-tax' present value of the asset with equity finance at year 0 is

$$\begin{aligned} PV(t)_0^{E,sld} &= (1-t)\int_0^\infty A_0 e^{-\{\alpha+r(1-t)\}u}\,du + t\int_0^\Gamma (C/\Gamma)e^{-r(1-t)u}\,du \\ &= \frac{A_0}{\alpha+r} + tC\left\{\frac{1-e^{-r(1-t)\Gamma}}{r(1-t)\Gamma} - \frac{\alpha}{\alpha+r(1-t)}\right\} \\ &= PV_0^E + tC\left\{\frac{1-e^{-r(1-t)\Gamma}}{r(1-t)\Gamma} - \frac{\alpha}{\alpha+r(1-t)}\right\} \end{aligned} \tag{5}$$

The application of *SLD* generates additional tax savings if $\frac{1-e^{-r(1-t)\Gamma}}{r(1-t)\Gamma} > \frac{\alpha}{\alpha+r(1-t)}$.

If the same investment is financed by debt completely, then

$$PV(t)_0^{\mathrm{F,SLD}} = (1-t)\int_0^{\infty} A_0 e^{-\{\alpha + r(1-t)\}u}\,\mathrm{d}u - (1-t)\int_0^{s} rCe^{-r(1-t)u}\,\mathrm{d}u + t\int_0^{\Gamma} (C/\Gamma)e^{-r(1-t)u}\,\mathrm{d}u = PV(t)_0^{\mathrm{E,SLD}} - r(1-t)C\left\{\frac{1-e^{-r(1-t)s}}{r(1-t)}\right\} = PV(t)_0^{\mathrm{E,SLD}} - \{1-e^{-r(1-t)s}\}C \quad (6)$$

With $0 < r < 1, 0 < t < 1$ and $s > 0$, the term $1 - e^{-r(1-t)s}$ is always smaller than 1. Therefore $PV(t)_0^{\mathrm{E,SLD}} > PV(t)_0^{\mathrm{F,SLD}}$.

Furthermore

$$NPV(t)_0^{\mathrm{F,SLD}} = PV(t)_0^{\mathrm{F,SLD}} - Ce^{-rs} = PV(t)_0^{\mathrm{E,SLD}} - \{1-e^{-r(1-t)s}\}C - Ce^{-rs} = NPV(t)_0^{\mathrm{E,SLD}} + e^{-rs}(e^{rts}-1)C \quad (7)$$

When $0 < r < 1$, $0 < t < 1$ and $s > 0$, the conditions $0 < e^{-rs} < 1$ and $e^{rts} > 1$ apply. As a consequence, $NPV(t)_0^{\mathrm{F,SLD}}$ is always larger than $NPV(t)_0^{\mathrm{E,SLD}}$.

As shown in Table 1, R&D investment of firms is most commonly promoted in OECD countries by allowing specific tax allowances and tax credits, which are often combined with one of more generous tax depreciation rules (i.e. geometric-degressive and free depreciations) than those applied for 'normal' investments. In 2006, for instance, the British R&D-specific tax concession consisted of tax allowance (*TA*) as a percentage share of current investment volume *C* combined with free depreciation (*FD*), while the normal investment was promoted by geometric-degressive depreciation (*GDD*) in this country. When equity financing of R&D investment, *NPV*(*t*) equipped with *TA* and *FD* at the year 0 can be expressed as follows

$$NPV(t)_0^{\mathrm{E},TA+FD} = (1-t)\int_0^{\infty} A_0 e^{-\{\alpha + r(1-t)\}u}\,\mathrm{d}u + t\int_0^{1} (\beta C)e^{-r(1-t)u}\,\mathrm{d}u + t\int_0^{1} Ce^{-r(1-t)u}\,\mathrm{d}u - C = PV_0^E + tC\left[\frac{\beta\{1-e^{-r(1-t)}\}}{r(1-t)} + \frac{1-e^{-r(1-t)}}{r(1-t)} - \frac{\alpha}{\alpha + r(1-t)}\right] - C \quad (8)$$

where β = the rate of *TA* which can be deducted from the tax base at year 1 $(0 < \beta)$.[6] Moreover, the total investment cost C is fully written off at year 1 since *FD* is applied.

Analogous to equation (7), with debt financing

$$NPV(t)_0^{\mathrm{F},TA+FD} = NPV(t)_0^{E,TA+FD} + e^{-rs}(e^{rts} - 1)C \tag{9}$$

Hence, the 'additional' investment promotion effect of an R&D-specific tax concession over *GDD* provided for normal investment in the UK is, with internal equity finance

$$\begin{aligned} NPV(t)_0^{\mathrm{E},\ TA+FD} &- NPV(t)_0^{\mathrm{E},\ GDD} \\ &= NPV(t)_0^{\mathrm{E},\ TA+FD} - \left[(1-t)\int_0^{\infty} A_0 e^{-\{\alpha+r(1-t)\}u}\,\mathrm{d}u \right. \\ &\quad \left. + tC\int_0^{\infty} \delta e^{-\{\delta+r(1-t)\}u}\,\mathrm{d}u - C\right] \\ &= NPV(t)_0^{\mathrm{E},TA+FD} - \left[PV_0^E + tC\left\{\frac{\delta}{\delta+r(1-t)} - \frac{\alpha}{\alpha+r(1-t)}\right\} - C\right] \end{aligned} \tag{10}$$

where δ = the *GDD* rate $(0 < \delta < 1)$ and $Ce^{-\delta u}$ = the net book value of capital good in the period u.[7]

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[6] Analogously, the present value of tax saving that is generated by the deduction of an R&D-specific tax credit (*TC*) as a percentage share of current investment volume C from the payable tax amount at year 0 can be described as

$$TS(t)_0^{TC} = t\int_1^0 \gamma Ce^{-r(1-t)u}\,\mathrm{d}u = t\gamma C\left\{\frac{1-e^{-r(1-t)}}{r(1-t)}\right\} \tag{F.1}$$

where γ = the rate of *TC* $(0 < \gamma < 1)$. Similar to the case with *TA*, equation (F.1) can also be combined with various tax depreciation rules. For example, with *FD* (as was the case in Canada, France and the Netherlands in 2006) equation (8) can be modified correspondingly to

$$\begin{aligned} NPV(t)_0^{\mathrm{E},TC+SLD} &= (1-t)\int_0^{\infty} A_0 e^{-\{\alpha+r(1-t)\}u}\,\mathrm{d}u + t\int_0^1 Ce^{-r(1-t)u}\,\mathrm{d}u + \int_0^1 \gamma Ce^{-r(1-t)u}\,\mathrm{d}u - C \\ &= PV_0^E + tC\left\{\frac{1-e^{-r(1-t)}}{r(1-t)} - \frac{\alpha}{\alpha+r(1-t)}\right\} + \frac{\gamma C\{1-e^{-r(1-t)}\}}{r(1-t)} - C \end{aligned} \tag{F.2}$$

In the case of adopting incremental *TA* and/or *TC*, their amounts are determined as a percentage share of a firm's R&D spending increase (Y) over some base period, instead of C.

[7] If $\delta = \alpha$, then $PV(t)_0^{\mathrm{E},GDD} = PV_0^E$. When $\delta < \alpha$, the corporate tax system does not provide any incentives at all regardless of the level of tax rate $(0 < t < 1)$ and, therefore, the condition $PV(t)_0^{\mathrm{E},\ GDD} < PV_0^{\mathrm{E}}$ prevails. With $\delta > \alpha$, $PV(t)_0^{\mathrm{E},\ GDD} > PV_0^{\mathrm{E}}$ applies, which, in turn, means that *GDD* provides incentives in combination with t. In this case a corporate tax rate t_{max} exists, which maximises $NPV(t)_0^{\mathrm{E},GDD}$ (see also Nam & Radulescu, 2005):

$$t_{\max}^{\mathrm{E},\ GDD} = \frac{\alpha\delta + \alpha r + \delta r + r^2 - (\alpha^2\delta^2 + \alpha^2\delta r + \alpha\delta^2 r + \alpha\delta r^2)^{1/2}}{\alpha r + r^2 + \delta r} \tag{F.3}$$

On the other hand, with debt finance

$$NPV(t)_0^{\text{F},\ TA+FD} - NPV(t)_0^{\text{F},\ GDD}$$
$$= NPV(t)_0^{\text{E},\ TA+FD} + e^{-rs}(e^{rts} - 1)C - \left\{NPV(t)_0^{\text{E},\ GDD} + e^{-rs}(e^{rts} - 1)C\right\}$$
$$= NPV(t)_0^{\text{E},\ TA+FD} - NPV(t)_0^{\text{E},\ GDD} \quad (11)$$

Taking the UK as an example, the comparison of equations (10) and (11) demonstrates that the additional investment promotion effect of generous R&D-specific tax concessions (and their combinations) over that of other standard tax depreciations allowed for normal investment projects remains unchanged, regardless of whether investment cost is covered by internal equity or debt.

4. Major Results of Model Simulation

Under the consideration of different financial methods of R&D investments, this empirical section compares the effects of R&D-specific tax incentives on a firm's after-tax NPV in 19 selected OECD countries for the year 2006. Two types of tax policy measures – statutory corporate tax rates and preferable tax treatment of R&D investment shown in Table 2 – differ from one country to another in the model simulation, whereas other relevant parameters such as real interest rate, economic depreciation, etc are given. Common assumptions made in the simulations are $A_0 = 100$; $r = 5\%$, $\alpha = \delta^* = 20\%$, $C = PV_0 = 400$, $\Gamma = 10$ years for R&D equipment, while incremental R&D tax credits and/or allowances are calculated based on $Y = 200$.

Basically two different types of calculations on investment promotion effects are carried out in this empirical part: the first after-tax NPV computation for the case when the amount of R&D tax allowance and tax credit is measured on the basis of current investment volume $C(= 400)$, and the second when its determination is made based on investment increment Y. Due to such a difference in the calculation basis, a direct comparison of these two cases to each other appears to be less meaningful and, as already mentioned above, the amount of Y is assumed to be 200, far smaller than C. In the countries where generous R&D-specific tax depreciation (like free depreciation) prevails, tax allowance or tax credit is combined with this R&D-specific depreciation rule when calculating the cumulative after-tax NPV. In the absence of such a depreciation rule, the 'normal' tax depreciation applies for the same purpose. The after-tax NPV can also be determined solely by tax saving generated from generous R&D-oriented depreciation rules if the investigated countries are not equipped with the matching tax allowance and tax credit system.

First, taking the British R&D promotion system as an example, Table 3 illustrates the changes of after-tax NPV according to the variation of the corporate tax rate t. Such a numerical analysis is interesting, since equation (F.3) in Footnote 7 suggests, unlike the conventional wisdom, the possibility of existing t_{max} with which $NPV(t)_0^{\text{E},\ GDD}$ reaches maximum. With $\delta = 25\%$, column (II) shows that $NPV(t)_0^{\text{E},\ GDD}$ is a $\cap$–shaped function of t and its amount is the highest

Table 3. Effects of tax incentives for R&D investment classified into corporate tax rate

	Without R&D-specific tax incentives			With R&D-specific tax incentives			
Corporate tax rate (%)	$TS(t)_0^{\mathrm{GDD}}$ ($\delta = 25\%$) (I)	$\mathrm{NPV}(t)_0^{\mathrm{E},GDD}$ (II)	$NPV(t)_0^{\mathrm{F},GDD}$ (III)	$TS(t)_0^{FD}$ (IV)	$TS(t)_0^{TA}$ ($TA = 125\%$)* (V)	$NPV(t)_0^{\mathrm{E},TA+FD}$ (VI)	$NPV(t)_0^{\mathrm{F},TA+FD}$ (VII)
5	0.6	0.6	7.6	3.4	24.4	27.8	34.7
10	1.2	1.2	15.7	6.5	48.9	55.4	69.8
15	1.8	1.8	24.3	9.3	73.4	82.7	105.2
20	2.3	2.3	33.5	11.8	98.0	109.8	141.0
25	2.7	2.7	43.4	13.9	122.7	136.6	177.2
30	3.1	3.1	53.9	15.8	147.4	163.2	213.9
35	3.5	3.5	65.1	17.3	172.2	189.5	251.1
40	3.7	3.7	77.1	18.5	197.0	215.5	288.9
45	3.9	3.9	90.0	19.3	221.9	241.2	327.3
50	4.0	4.0	103.7	19.7	246.9	266.6	366.3
55	4.1	4.1	118.5	19.8	271.9	291.7	406.1
60	4.0	4.0	134.3	19.4	297.0	316.5	446.7
65	3.9	3.9	151.3	18.7	322.2	340.8	488.2
70	3.7	3.7	169.5	17.4	347.4	364.8	530.6
75	3.4	3.4	189.0	15.8	372.7	388.4	574.1
80	2.9	2.9	210.0	13.6	398.0	411.7	618.7
85	2.4	2.4	232.5	11.0	423.4	434.4	664.6
90	1.7	1.7	256.8	7.9	448.9	456.8	711.8
95	0.9	0.9	282.8	4.2	474.4	478.6	760.5

Note: TS = tax savings; GDD = geometric-degressive depreciation; FD = free depreciation; TA = tax allowances.
* R&D tax allowance is calculated as a percentage share of current investment volume and also combined with FD.
Common assumptions made in the simulations are $A_0 = 100$, $r = 5\%$, $\alpha = 20\%$, $C = PV_0 = 400$, $\Gamma = 10$ years for R&D equipment.
Source: Author's own calculations.

when t is around 55%. A similar trend can also be observed in column (IV) with $TS(t)_0^{FD}$, when free depreciation is introduced as a R&D-specific incentive measure. For a given t, a comparison of difference between columns (III) and (II) on the one hand, and that made between columns (VI) and (VII) on the other, confirm that $NPV(t)_0^{\mathrm{F},\,GDD} - NPV(t)_0^{\mathrm{E},\,GDD} = NPV(t)_0^{\mathrm{F},\,FD+TA} - NPV(t)_0^{\mathrm{E},\,FD+TA}$. Column (III) additionally highlights that ceteris paribus $NPV(t)_0^{F,GDD}$ continuously grows with t. This fact, in turn, signals that the investment promotion effect led by debt finance gets more rapidly larger than $TS(t)_0^{GDD}$ changes, when t increases. A comparable development is also observed for $TS(t)_0^{TA}$ as well as $NPV(t)_0^{\mathrm{E},\,FD+TA}$ and $NPV(t)_0^{\mathrm{E},\,FD+TA}$ in columns (V), (VI) and (VII) in the same table, for which the positive effect of 125% R&D-specific tax allowances play a dominant role in particular. These empirical findings have a somewhat adverse tax policy implication, namely that by given depreciation rules or R&D-specific tax incentives, a more intensive promotion of firms' (R&D-specific) investments can be achieved in combination with a higher t.

Among the surveyed OECD countries, Germany, Poland and Sweden treated the R&D investment activities of private firms the same as different types of capital formation in 2006. Under the assumption of relevant parameters made above, the German and the Polish corporate tax rules did not provide any incentives at all when the R&D investment is financed by internal equity – a fact that is expressed in terms of negative $NPV(t)_0$ values in column (VII) of Table 4.

Columns (VIII) and (XI) of Table 4 demonstrate the after-tax NPV of OECD members when the rates of R&D tax incentive measures are calculated on the basis of current investment volume (i.e. $C = 400$): the former column shows the case with internal equity finance and the latter with debt finance. Although free depreciation applied in countries like France, the UK, and Canada also played a certain role in 2006, R&D-specific *TA* was the incentive measure that generated the most substantial tax saving (see also column III). In this year, the top after-tax NPV ranking group was led by the Czech Republic and consisted of Belgium, the UK, Denmark, Hungary and Austria as well as Australia, in descending order – all these countries had a generous *TA* scheme. Equipped with *TC*, Canada, Portugal, Spain and the Netherlands were in the middle ranking group, while Luxembourg with the sole R&D-oriented GDD of 40% was in last position among the 15 OECD countries shown in columns (VIII) and (XI) of Table 4.

If the rates of tax allowance and tax credit are exclusively imposed on the incremental sum of investment ($Y = 200$), the country ranking of the after-tax NPV is differently structured. Again, in spite of the absence of an incremental *TC* and *TA* system, the lowest ranked countries, such as Hungary, Luxembourg, Belgium, Canada, the Netherlands and the UK, are also illustrated in columns (IV) and (XII) of Table 4, since they had R&D-specific depreciation. Regardless of whether the R&D investment is financed by internal equity or debt, for example, the sole application of the *SLD* of 20% made Hungary (together with Luxembourg) place at the bottom of country rankings in 2006. Unlike the case with volume-based computation, however, the countries with a generous *TC* on Y, such as France, Portugal and Spain, ranked at the top, followed by Australia and Austria endowed with the incremental *TA*.

Table 4. Comparison of effects of tax incentives for R&D investment in OECD countries in 2006

Country	$TS(t)_0$ with normal DR (I)	$TS(t)_0$ with R&D specific DR (II)	$TS(t)_0^{TA}$ Current volume ($C = 400$) (III)	$TS(t)_0^{TA}$ Increment ($Y = 200$) (IV)	$TS(t)_0^{TC}$ Current volume ($C = 400$) (V)	$TS(t)_0^{TC}$ Increment ($Y = 200$) (VI)	$NPV(t)_0$, equity finance: With normal DR (VII)	$NPV(t)_0$, equity finance: With R&D specific incentives* Current volume ($C = 400$) (VIII)	$NPV(t)_0$, equity finance: With R&D specific incentives* Increment ($Y = 200$) (IX)	NPV$(t)_0$, debt finance: With normal DR (X)	NPV$(t)_0$, debt finance: With R&D specific incentives Current volume ($C = 400$) (XI)	NPV$(t)_0$, debt finance: With R&D specific incentives Increment ($Y = 200$) (XII)
Australia	0.0	–	122.7	85.9	–	–	0.0	122.7	85.9	40.6	163.3	126.5
Austria	−0.8	–	122.7	66.3	31.4	–	−0.8	155.3	65.5	39.8	195.9	106.1
Belgium	0.0	12.8	151.8	–	–	–	0.0	164.6	12.8**	59.4	224.0	72.2**
Canada	4.3	12.7	–	–	78.5	–	4.3	91.2	12.7**	39.3	126.3	47.8**
Czech Rep.	−0.8	–	188.4	–	–	–	−0.8	187.6	–	37.9	226.3	–
Denmark	3.0	–	165.0	–	–	–	3.0	168.0	–	49.6	214.6	–
France	1.8	16.8	–	–	19.7	88.5	1.8	36.5	105.3	59.7	94.3	163.1
Germany	−0.8	–	–	–	–	–	−0.8	–	–	39.8	–	–
Hungary	−0.7	6.0	160.8–321.6	–	–	–	−0.7	166.8–327.6	6.0**	31.4	198.9–359.7	38.1**
Ireland	3.9	7.9	–	–	–	39.1	3.9	7.9**	47.0	22.3	26.3**	65.4
Japan	0.0	–	–	–	39.3–59.0	–	0.0	38.3–59.0	–	50.7	89.0–109.7	–
Luxembourg	−0.8	6.8	–	–	–	–	−0.8	6.8**	6.8**	35.8	43.4**	43.4**
Netherlands	−0.8	13.9	–	–	55.0	–	−0.8	68.9	13.9**	39.8	109.5	54.5**
Poland	−0.7	–	–	–	–	–	−0.7	–	–	28.7	–	–
Portugal	2.8	7.2	–	–	78.5	98.2	2.8	85.7	105.4	43.3	126.3	146.0
Spain	−0.9	–	–	–	78.7	98.4	−0.9	77.8	97.5	60.7	139.4	159.1
Sweden	5.1	–	–	–	–	–	5.1	–	–	51.7	–	–
UK	3.1	15.8	147.4	–	–	–	3.1	163.2	15.8**	53.9	213.9	66.5**
USA	0.0	–	–	–	–	39.4	0.0	–	39.4	61.6	–	101.0

Note: TS = tax savings; DR = depreciation rules.
* In the case of absence of R&D-specific DR, the R&D allowances and R&D tax credits are combined with the normal DR.
** Only with R&D-specific depreciation rules.
Common assumptions made in the simulations are $A_0 = 100$; $r = 5\%$, $\alpha = 20\%$, $C = PV_0 = 400$, $\Gamma = 10$ years for R&D equipment, and $Y = 200$ for the case that incremental R&D tax credits and/or allowances are applied.
Source: Table 2 and author's own calculations.

5. Conclusion

This study deals with the preferential tax treatment of R&D investment in selected OECD countries. Many member countries have exceptionally kept and even extended such a tax-base subsidy system as an important technology and innovation policy measure, although they have recently carried out a series of 'tax-rate-cut-cum-base-broadening' corporate tax reforms. This fact suggests that there has been a sort of tax competition among the OECD countries regarding R&D promotion.

Clearly differentiating financing methods between internal equity and debt finance, this study computes and compares the after-tax NPV in order to identify the generosity of various types of tax incentives implemented in OECD countries that are aimed at stimulating firms' R&D investments in the context of a corporate tax system. Analogous to many other previous research findings, this study also confirms that the corporate tax system favours debt finance, since by a given tax depreciation scheme the absolute amount of after-tax NPV with debt finance exceeds that with internal equity finance. Yet, the major reasons for the superiority of debt finance encompass more than the conventional deductibility of interest payment from the tax base, which creates extra tax savings. For example, with debt finance, annual gross profits are also reduced by the amount of interest payments, from which the entire corporate tax burden is subtracted to calculate the post-tax profits. Moreover, compared to the investment cost covered by firms' internal equity, the present value of debt-financed investment cost considered in the calculation of the after-tax NPV is lower, since discounting (with the real interest rate) occurs for the repayment of the entire debt sum at the end of the given maturity years. However, the preponderance of internal equity finance for R&D investment can hardly be explained in relation to the corporate tax incentive system, because the additional promotion effects (also expressed in terms of the post-tax NPV) of generous R&D-specific tax incentives over the standard depreciation rules (allowed for usual fixed capital investments) in the individual OECD countries, remain unchanged regardless of the financing method.

The OECD comparison demonstrates that R&D tax allowances were the incentive measure that generated the most substantial tax savings in 2006. In this year the top after-tax NPV ranking group was led by the Czech Republic, followed by Belgium, the UK, Denmark, Hungary and Austria as well as Australia – all these countries had a R&D allowance scheme. Endowed with R&D tax credit, Canada, Portugal, Spain and the Netherlands belong to the middle ranking group. Notably, with such tax allowances and tax credits, the after-tax NPV ceteris paribus increases with the corporate tax rate. This positive correlation, in turn, suggests the possibility of achieving a stronger R&D investment promotion by adopting a 'tax-rate-*increase*-cum-base-broadening' policy, instead of the tax-rate-cut-cum-base-broadening type that is dominant in OECD countries.

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