Int Tax Public Finance (2008) 15: 563–581
DOI 10.1007/s10797-007-9039-7

Measuring tax incentives for R&D

Kenneth J. McKenzie

Published online: 27 June 2007

Abstract A methodology for measuring the user cost of intangible R&D capital is developed. In contrast to the way in which the Hall–Jorgenson–King–Fullerton (HJKF) approach to measuring the user cost of capital, and the related notion of the effective marginal tax rate on capital, is typically applied to intangible R&D capital, the methodology takes explicit account of the microeconomic foundations of R&D in order to aggregate the user costs of the various inputs used in the production of R&D. Illustrative calculations are presented for Canadian provinces which show that relative to the methodology developed here, the standard approach substantially overstates the tax subsidy offered to intangible R&D capital.

Keywords Research and development · Technological change · Tax incentives · Cost of capital · Effective marginal tax rate

JEL Classification H2 · O3

1 Introduction

It is well accepted that technological innovation is an endogenous process that responds to economic incentives.[1] While modern treatments differ in the way that technological change emerges, investment in research and development (R&D) plays a prominent role in much of the literature.[2]

[1]The modern genesis of this view is found in the endogenous growth literature. See Romer (1994) for a retrospective and Aghion and Howitt (1998), Grossman and Helpman (1991), and Barro and Sala-i-Martin (1995) for text book treatments.

[2]The survey by Griliches (1988) documents R&D as an important source of technological change.

K.J. McKenzie (✉)
Department of Economics, University of Calgary, 2500 University Drive N.W., Calgary, AB, Canada, T2N 1N4
e-mail: ken.mckenzie@ucalgary.ca

Like investment in tangible (physical) capital, investment in intangible R&D capital is a costly process undertaken by profit maximizing firms. However, R&D has some important characteristics that are not shared by other types of capital (at least to the same extent). The characteristic that has received the most attention, both theoretically and empirically, is the presence of externalities, or spillovers, associated with R&D. These spillovers suggest a discrepancy between the private and social rates of return to R&D. Some researchers estimate this discrepancy to be quite substantial.[3]

The presence of spillovers suggests scope for government subsidies for R&D. A favored mechanism for delivering these subsidies is the tax system, and indeed many countries, and regions within countries, offer quite significant tax breaks for expenditures related to R&D. This raises the important issue of how to properly measure these tax subsidies, and the overall effective rate of taxation on R&D capital.

In addition to its potential for spillovers, another distinguishing feature of R&D is that investment in intangible R&D capital tends to be a 'non-marketed' input into either the production or product development process.[4] 'Non-marketed' in this context means that intangible R&D capital is not purchased for a price determined by the market, like physical capital, but rather is produced within the firm by way of a "R&D production function" using inputs such as labor (scientists), materials (test tubes) and physical capital (microscopes and laboratories). The resulting stock of intangible R&D capital (knowledge) then enters either the production or product development process.[5]

Most studies that analyze the taxation of tangible capital employ the notion of the tax adjusted user cost of capital pioneered by Hall and Jorgenson (1967). The closely related concept of the effective marginal tax rate (EMTR) on capital, due to King and Fullerton (1984), has spawned numerous studies that compute and compare effective tax rates across sectors, assets and jurisdictions.[6] The standard Hall–Jorgenson–King–Fullerton (HJKF) approach followed in these studies is to calculate an overall cost of capital or EMTR by taking a weighted average of the different types of capital.

The tendency in the existing literature is to apply a similar approach to intangible capital such as R&D. The standard approach is to treat expenditures on inputs employed in the production of intangible R&D capital as different types of R&D capital in and of themselves, and then take a weighted average to determine the overall user cost or EMTR of R&D capital.[7]

[3] See, for example, Griliches (1992) and Bernstein (1996).

[4] Another distinguishing characteristic of R&D is that investments tend to be both highly risky and largely irreversible. The implications of risk and irreversibility for the measurement of the cost of capital and effective marginal tax rates are examined by McKenzie (1994). While it is possible to include these factors in the model developed here, they needlessly complicate the analysis and obfuscate the main point.

[5] R&D need not be produced in-house, but rather may be contracted out to an R&D services company. This does not change the fact that intangible R&D capital, as opposed to R&D inputs, cannot be purchased on the market since the R&D contractor charges for the input (e.g., dollars per hour of service) rather than charging for the finished output—R&D capital.

[6] See, for example, King and Fullerton (1984), Boadway et al. (1984) and, more recently, Mackie (2002).

[7] See, for example, Wilson (2005), Griffith et al. (1995), Gordon and Tchilinguirian (1998), and Mackie (2002).

By treating R&D inputs as intangible R&D capital, these studies ignore the underlying microeconomic foundations of the R&D process. The contribution of this paper is to show how the true user cost and EMTR of intangible R&D capital can be constructed via an aggregation function based on the R&D production function. The paper, therefore, shows how the HJKF approach can be applied to intangible R&D capital in a way that is consistent with its microeconomic foundations.

As an illustration, the methodology is applied to Canadian provinces. Comparing these calculations to the standard approach, it turns out that it makes a big difference. In particular, the standard weighted average approach typically used in the literature substantially overstates the tax subsidy to R&D.

Viewing R&D as an intangible asset that is produced in-house not only reflects the process underlying R&D, but is consistent with the way that tax incentives are actually delivered. These incentives are based on the expenditures on the inputs used in the process of conducting, or producing, R&D (labor, materials, physical capital), not on the R&D capital itself. Moreover, not only does the tax treatment vary across these inputs, but so do the characteristics of the inputs themselves, labor and materials being of the nature of current inputs while equipment and buildings are of the nature of capital inputs into the R&D production process.

The measurement of tax incentives for R&D in a way that is consistent with its microeconomic foundations is important. The tax treatment of R&D is often quite complex and varies substantially across jurisdictions. As such, the measurement of R&D tax incentives is not a straightforward matter. The development of an economically sensible methodology for measuring R&D tax incentives is the obvious first step in addressing the difficult task of determining the appropriate level of subsidy to provide. Moreover, empirical investigations of the efficacy of R&D tax incentives, particularly those using cross-sectional data from different countries, or regions, require that these incentives be measured in an economically sensible and comparable manner.[8]

The remainder of the paper is organized as follows. In Sect. 2, a dynamic model of a profit maximizing firm that undertakes R&D in-house is described and the expressions for the cost of capital and EMTR on intangible R&D capital are derived. In Sect. 3, illustrative EMTR calculations for Canadian provinces are presented and discussed. Section 4 offers a summary and conclusions.

2 The model

In this section, the methodology for evaluating R&D tax incentives is developed within the context of a dynamic neo-classical model of a profit maximizing firm. To begin, consider a firm that produces revenue according to the function $R(X, A)$, where X is a vector of tangible inputs used in the production of the firm's output and A is the stock of intangible R&D capital accumulated within the firm. As the focus is

[8]Empirical studies of the effectiveness of R&D tax incentives using the weighted average cost of capital approach include Wilson (2005), Bloom et al. (2002), Hall (1993), Hines (1993) and Bernstein (1986).

on investment in intangible R&D capital, the vector X is ignored in what is to follow, and we just write $R(A)$; this has no impact on the subsequent analysis.

This formulation is general in that it allows for both "process" and "product" R&D. Process R&D affects the revenue function by way of the production function embodied in $R(A)$. Product R&D that enhances product quality or diversity affects the revenue function through higher revenues, via the demand function (i.e., the price) for the firm's output embodied in $R(A)$. Thus, the formulation makes no assumptions about market structure. While the form of the revenue function will differ in alternative competitive environments, the expressions for the cost of capital and the effective tax rates derived below will remain unchanged. All that is required for our purposes is that the revenue function be concave.[9]

Intangible R&D capital (A) is a non-marketed input that is not purchased on the market by the firm but rather is produced in-house according to the function $G(L, K)$, where L is the amount of labor employed in R&D (scientists), and K is the amount of tangible capital (microscopes, labs). Note that L is a current input in the production of R&D while K is an enduring input that evolves over time according to:

$$\dot{K} = I - \delta_K K, \tag{1}$$

where I is the amount of investment in physical capital used in the production of R&D and δ_K is the physical depreciation rate on that capital.

The stock of intangible R&D capital produced within the firm also has enduring value, and evolves according to:

$$\dot{A} = G(L, K) - \delta_A A, \tag{2}$$

where δ_A is the rate at which R&D capital depreciates.[10]

The present value of the after-tax operating cash flows of the firm is:

$$V = \int_0^\infty \mathrm{e}^{-\rho t}\left[R(A)(1-u) - w(1+T_L)L - q(1+T_K)I\right]\mathrm{d}t, \tag{3}$$

where ρ is the discount rate, q is the unit price of capital used in the production of R&D, w is the wage rate, and u, T_L and T_K are taxed parameters explained below.

The corporate income tax rate is u, therefore $R(A)(1-u)$ is after-tax revenue. The tax treatment of R&D expenditures depends, of course, on the jurisdiction and the type of expenditure. It appears universal that current expenditures on labor (wL) used in the production of R&D are, like other current inputs, immediately expensed. Labor may also be subject to payroll taxes, personal income taxes, and sales taxes, some share of the burden of which will be borne by businesses.[11] R&D labor costs

[9] Ambec and Poitevin (2001) take a similar approach.

[10] Nadari and Prucha (1993), estimate that the economic depreciation rate for R&D is approximately 10%. This is the value used in the calculations presented in the next section. Note that this depreciation rate is conceptually different from the physical depreciation rate on tangible capital used in the production of intangible R&D capital.

[11] The share of the taxes on labor borne by firms depends upon its economic incidence, which is a function of the relative elasticities of the labor demand and supply curves. It is presumed in the calculations that

may also be eligible for tax credits and investment allowances. To account for all of this in a general way, and without going into the details of a particular tax system, the after-tax cost of a one dollar expenditure on R&D labor is denoted $(1 + T_L)$, where T_L depends upon the specific details of the tax system.[12]

The tax system as it relates to tangible capital used in the production of intangible R&D capital is treated in a similar manner, where the after-tax cost of a one dollar expenditure on R&D capital is $(1 + T_K)$. Because tangible capital is an enduring input, and various features of the tax system may result in a flow of credits or allowances claimed over time (such as tax depreciation allowances), T_K may reflect the present value of these tax deductions, credits, and allowances.[13]

The discount rate, ρ, is the opportunity cost of equity.[14] The so-called "traditional" view of dividends and capital gains taxation is adopted—see Poterba and Summers (1985), Zodrow (1991) or Auerbach (2002)—which yields a before-tax required rate of return on equity of,

$$\rho = \frac{i(1 - t_\mathrm{i})}{1 - t_\mathrm{e}}, \tag{4}$$

where i is the nominal interest rate, t_i is the personal tax rate on interest income and t_e is the effective personal tax rate on equity. The latter is a weighted average of the effective tax rate on dividends, θ, and the accrual equivalent effective tax rate on capital gains, c. Thus, $t_\mathrm{e} = \gamma\theta + (1 - \gamma)c$ where γ is the dividend payout ratio.[15]

A key point from the above discussion is that not only do the inputs used in the production of R&D potentially differ in their tax treatment, but they differ in their economic characteristics, labor being *current* in nature and capital being *enduring* in nature. These inputs combine to produce an intangible asset—knowledge, or intangible R&D capital—which is of enduring value and produces a flow of revenue over time. As shall be made clear in what follows, it is the cost of capital, and the tax wedge or EMTR, on this asset—intangible R&D capital created within the firm—that is of primary interest from a policy perspective.

Before proceeding, it is worth pointing out that the basic idea behind the formulation is consistent with many endogenous growth models that incorporate a role for R&D. In these models, R&D is typically produced in-house using labor as the only input.[16] The formulation developed here generalizes this idea by allowing a capital

follow below that businesses bear one-third of the burden of taxes on labor. This is based on an assessment of the empirical literature by Dahlby (1996).

[12]For example, if business's share of payroll, personal income and sales taxes is t_L, labor is expensed for corporate income tax purposes and receives an R&D tax credit granted at rate ϕ, then $1 + T_L = (1 + t_L)(1 - u)(1 - \phi)$.

[13]For example, if Z is the present value of the flow of tax depreciation deduction on one dollar of capital used in R&D, and expenditures on capital used in R&D receive a tax credit at rate ϕ, then $(1 + T_K) = (1 - uZ)(1 - \phi)$. If expenditures on capital are expensed, as is the case for R&D equipment in Canada, then $Z = 1$.

[14]It is assumed that the firm is all equity financed, with no debt.

[15]As indicated, this is reflective of the so-called "traditional" view of dividends and capital gains taxation. Again, see Poterba and Summers (1985) and Zodrow (1991). The "classical" view can be accommodated by setting $\gamma = 0$.

[16]See, for example, Grossman and Helpman (1991).

input to be used in the production of R&D. Although the spirit behind this characterization is well established in the endogenous growth literature, it is not reflected in the effective tax rate and cost of capital research that seeks to measure tax incentives for R&D.

To proceed, it is useful to re-express the problem with the firm choosing the amount to invest in intangible R&D capital in each period so as to:

$$\text{Max} \int_0^\infty \mathrm{e}^{-\rho t}\big[R(A)(1-u) - C\big(G; w(1+T_L), q(\rho+\delta_A)(1+T_K)\big)\big]\,\mathrm{d}t, \tag{5}$$

subject to:

$$\dot{A} = G - \delta_A A, \tag{6}$$

where $C(G; w(1+T_L), q(\rho+\delta_A)(1+T_K))$ is the contemporaneous after-tax minimized cost of producing intangible R&D capital, which is a function of the amount of R&D capital produced in each period (G), and the after-tax costs of the inputs used to produce it: labor ($w(1+T_L)$) and capital ($q(\rho+\delta_K)(1+T_K)$).[17]

The first-order conditions are:

$$\lambda = MC\big(G; w(1+T_L), q(\rho+\delta_A)(1+T_K)\big), \tag{7}$$

$$-\dot{\lambda} = \frac{\partial R(\cdot)}{\partial A}(1-u) - \gamma(\rho+\delta_A), \tag{8}$$

where λ is the costate-variable associated with the equation of motion for the stock of intangible R&D capital and,

$$MC\big(G; w(1+T_L), q(\rho+\delta_A)(1+T_K)\big) \equiv \frac{\partial C(G; w(1+T_L), q(\rho+\delta_A)(1+T_K))}{\partial G}, \tag{9}$$

is the after-tax marginal cost of producing R&D capital.

Equations (7) and (8) can be used to determine an equation for the optimal steady state stock of intangible R&D capital (where $\dot{\lambda} = 0$):

$$\frac{\partial R(\cdot)}{\partial A} = \frac{MC(G; w(1+T_L), q(\rho+\delta_A)(1+T_K))}{1-u}(\rho+\delta_A). \tag{10}$$

The left-hand side of (10) is the before-tax return on a marginal unit of intangible R&D capital produced within the firm (the marginal revenue product of R&D capital), while the right-hand side is the tax adjusted user cost of R&D capital, which reflects the after-tax marginal cost of producing R&D.

Equation (10) can be written in a more convenient way. To do this, first define the effective marginal tax rates (EMTRs) on labor and capital used to produce R&D (τ_L

[17] This is obtained by choosing the amount of labor and capital so as to minimize the cost of producing a given amount of intangible R&D capital every period: Min $\int_0^\infty \mathrm{e}^{-\rho t}[w(1+T_L) + q(1+T_K)I]\,\mathrm{d}t$ subject to $\dot{K} = I - \delta_K K$ and $G = G(L, K)$.

and τ_K) as follows:

$$\tau_L \equiv \frac{w(1+T_L)/(1-u)-w}{w}, \tag{11}$$

$$\tau_K \equiv \frac{q(\rho+\delta_K)(1+T_L)/(1-u)-q(\rho+\delta_K)}{q(\rho+\delta_K)}. \tag{12}$$

In each case, the numerator is the wedge between the before- and after-tax return on the R&D input. Expressing this wedge relative to the before-tax return means that the EMTR measures the percentage increase in the user cost of the input due to the tax system. Thus, the EMTRs on the R&D inputs can be thought of as the effective excise tax rates on R&D labor and capital. These differ from the "standard" EMTRs in being normalized with respect to the before-tax return on the input, and (in the case of capital) by being expressed gross, rather than net, of depreciation.

In Appendix 1, it is shown that,

$$\frac{MC(G; w(1+T_L), q(\rho+\delta_A)(1+T_K))}{1-u} = MC\big(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K)\big), \tag{13}$$

where careful note should be taken of the distinction between T_L and τ_L for labor, and similarly for capital. The right-hand side of (13) is the marginal cost of producing a unit of intangible R&D capital expressed as a function of the EMTRs on the inputs into the R&D process.

Using (13), the equation defining the optimal stock of R&D capital (10) can now be written as,

$$\frac{\partial R(\cdot)}{\partial A} = MC\big(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K)\big)(\rho+\delta_A). \tag{14}$$

The fact that each input into the R&D process faces a different effective tax rate, and that the nature of the inputs themselves is different (i.e., current vs. capital), makes it potentially difficult to determine an *overall* effective tax rate on R&D. The typical approach in the literature has been to assume that the inputs used to produce R&D capital within the firm are in fact different types of R&D capital, and then take a simple weighted average of the individual EMTRs (this is discussed in more detail below). As discussed above, this not only ignores the different nature of current and capital inputs, but is inconsistent with the microeconomic foundations of R&D. Labor and capital are inputs into the production of intangible R&D capital, not R&D capital in and of themselves.

Following the groundwork laid above, however, it is possible to aggregate the EMTRs on the individual inputs used to produce R&D capital to generate an overall effective tax rate on intangible R&D capital in a way that is consistent with its microeconomic underpinnings.

As shown above, the after-tax marginal cost of producing intangible R&D capital is a function of the after-tax user cost of each input, which is in turn a function of the EMTRs on the inputs. Thus, taxes applied to the inputs affect the marginal cost of producing R&D capital through their impact on the after-tax user costs of the inputs. An economically meaningful way of aggregating the EMTRs on the individual inputs used to produce R&D is to determine the extent to which these EMTRs increase (or decrease in the case of a subsidy) the marginal cost of producing intangible R&D capital.[18]

Towards this end, the before-tax marginal cost of producing intangible R&D capital is obtained by evaluating that R&D marginal cost function at the before-tax user cost of the R&D inputs, $MC(G; w, q(\rho + \delta_K))$. Now define the *effective marginal tax rate on R&D costs* (EMTR on R&D costs) as the T_R that solves $MC(G; w, q(\rho+\delta_K))(1+T_R) = MC(G; w(1+\tau_L), q(\rho+\delta_K)(1+\tau_K))$, or,

$$T_R = \frac{MC(G; w(1+\tau_L), q(\rho+\delta_K)(1+\tau_K)) - MC(G; w, q(\rho+\delta_K))}{MC(G; w, q(\rho+\delta_K))}. \quad (15)$$

The EMTR on R&D costs measures the percentage change in the cost of producing an incremental unit of intangible R&D capital due to the taxation of the inputs into that production. It can be thought of as the effective excise tax rate applied to the production of intangible R&D capital within the firm.

To calculate the EMTR on R&D costs, as defined in (15), the R&D cost function must be parameterized. Consider, for example, a linearly homogeneous constant elasticity of substitution (CES) production function for R&D. In this case the EMTR on R&D costs is:

$$T_R = \left[\sum_i S_i(1+\tau_i)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} - 1, \quad (16)$$

where S_i is the factor share of R&D input i, and σ is the elasticity of substitution.

Two commonly used special cases of the CES production function are the Cobb–Douglas (CD) and Leontief, or fixed proportions (FP), production functions. The elasticity of substitution for the CD case is unity, in which case (16) reduces (in the limit) to,

$$T_R = \prod_i (1+\tau_i)^{S_i} - 1. \quad (17)$$

For the FP case, the elasticity of substitution is zero, and the EMTR on R&D costs becomes,

$$T_R = \sum_i S_i(1+\tau_i) - 1. \quad (18)$$

In the case of a CD production function there is some scope for substituting between factors in the production of R&D capital, and the EMTR on R&D costs reflects the geometric weighted average of the EMTRs on the inputs, which is lower than the arithmetic average. This is reflective of a more general consideration. It is easy to see from (16) that as the elasticity of substitution between the R&D inputs increases, the EMTR on R&D costs decreases. This is because as the degree of substitutability between inputs rises the firm is better able to respond to tax induced changes in relative factor prices by changing the input mix in order to produce a given amount of

[18] This basic idea was introduced in a different context by McKenzie et al. (1997).

R&D capital at minimum cost. As such, a tax induced increase in the relative price of an input has a lower impact on marginal costs the higher is the elasticity of substitution. A key issue here is the sensitivity of T_R to different assumptions regarding the elasticity of substitution; this will be addressed below.

With the concept of the EMTR on R&D costs in hand, it is now possible to express (14) in yet another way, as follows:

$$\frac{\partial R(\cdot)}{\partial A} = MC\big(G; w, q(\rho+\delta_A)\big)(1+T_R)(\rho+\delta_A). \tag{19}$$

The right-hand side is the tax adjusted user cost of intangible R&D capital. This differs from a standard user cost of capital expression in two ways. First, the presence of the term $MC(G; w, q(\rho+\delta_A))$, which is the before-tax marginal cost of intangible R&D capital, appears instead of the market price of a unit of R&D capital. This is because intangible R&D capital is not purchased on the market at some market determined price, but rather is produced in-house—the price of R&D capital is therefore the marginal cost of producing it. Second, the term $(1+T_R)$ represents the aggregation of the EMTRs on the inputs used to produce intangible R&D capital according to the R&D production function.

The left-hand side of (19) can be expressed as a rate of return by defining the gross-of-tax, net-of-depreciation, rate of return on a marginal unit of intangible R&D capital as $r_A^{g} \equiv (\partial R/\partial A)/MC(G; w, q(\rho+\delta_K)) - \delta_A$, which gives,

$$r_A^{g} = (1+T_R)(\rho+\delta_A) - \delta_A. \tag{20}$$

The tax wedge on intangible R&D capital is measured by taking the difference between the gross-of-tax rate of return on a marginal unit of R&D capital and its net-of-tax counterpart, or $r_A^{g} - \rho$. The tax wedge therefore measures the taxes paid on a marginal unit of R&D capital produced within the firm.

The *effective marginal tax rate on intangible R&D capital* (EMTR on R&D capital) is then determined in the standard way by expressing this wedge relative to the gross-of-tax, net-of-depreciation, rate of return, r_A^{g}, or,

$$\tau_A \equiv \frac{r_A^{g} - \rho}{r_A^{g}}. \tag{21}$$

The EMTR on R&D capital thus measures the proportion of the pre-tax (gross-of-tax) rate of return on a marginal investment in R&D that is needed to cover its taxes. It provides a measure of the extent to which the tax system provides an incentive, or disincentive, to invest in intangible R&D capital that is consistent with its microeconomic foundations.

Several effective tax rate concepts have been introduced in the derivation, and it is convenient to briefly summarize them here. Various features of the tax system as it relates to labor and capital give rise to EMTRs on the inputs into the R&D process (labor and capital). The EMTRs on these R&D inputs are then aggregated together in the EMTR on R&D costs. Finally, the EMTR on R&D costs is used in the determination of the user cost of intangible R&D capital and in the derivation of

Table 1 Effective marginal tax rate (EMTR) expressions for a CES R&D production function

EMTR on R&D labor (τ_L)	$1+\tau_L=(1+T_L)/(1-u)$
EMTR on physical R&D capital (τ_K)	$1+\tau_K=(1+T_K)/(1-u)$
EMTR on R&D costs for CES function (T_R)	$1+T_R=\{S_L(1+\tau_L)^{1-\sigma}+S_K(1+\tau_K)^{1-\sigma}\}^{1/(1-\sigma)}$
Gross-of-tax rate of return on a marginal unit of intangible R&D capital (r_A^g)	$r_A^g=(1+T_R)(\rho+\delta_A)-\delta_A$
EMTR on intangible R&D capital (τ_A)	$\tau_A=(r_A^g-\rho)/r_A^g$
Notation	
$1+T_L$	After-tax cost of a one dollar expenditure on R&D labor
$1+T_K$	After-tax cost of a one dollar expenditure on physical R&D capital
u	Corporate income tax rate
S_L	Labor's share of R&D costs
S_K	Capital's share of R&D costs
σ	Elasticity of substitution between R&D labor and physical capital
ρ	Required rate of return on equity
δ_A	Economic depreciation rate on intangible R&D capital

the EMTR on intangible R&D. By way of consolidation, and to gather the results, the equations determining the various EMTR concepts are reported for convenience in Table 1.

Before proceeding to some illustrative computations, it is useful to reflect for a moment on a few features of the model. The model is quite general in the sense that it allows for either perfect or imperfect competition in the output market, cost reducing process R&D, or product enhancing product R&D. The minimization of the cost of producing intangible R&D capital is, of course, independent of these considerations. While alternative formulations will affect the specific form of the r_A^g term on the left-hand side of (20), and therefore alter the equilibrium level of R&D undertaken by the firm, the tax adjusted user cost (the right-hand side), and therefore, the measurement of the tax wedge and EMTR on intangible R&D capital, is unchanged by these considerations. Thus, the approach adopted here is quite flexible.

It is also useful to highlight how the approach developed here differs from the standard approach to measuring the tax adjusted user cost of R&D capital and the EMTR on R&D capital. It does so in several ways. As indicated above, the approach adopted here is that various inputs—in our case, labor and capital—are used in the in-house production of intangible R&D capital. Importantly, these are inputs into the production of R&D capital, not R&D capital in and of themselves. Moreover, these inputs vary in their economic characteristics—labor is a current input and capital is an enduring input. The intangible R&D capital produced with these inputs is of enduring value. These inputs are aggregated together by way of an R&D production function, and the resulting user cost of intangible R&D capital reflects this aggregation function. Thus, unlike the weighted average approach typically used in the literature, the model takes explicit account of the microeconomic underpinnings of R&D.

Under the standard approach labor and tangible capital used in the production of intangible R&D capital are treated as different types of R&D capital in and of themselves, and the user costs are aggregated together by taking a simple weighted average. In terms of the above framework, under the standard approach each type of "R&D capital", i, has gross rate of return given by:

$$r_i^g = \frac{(1 + T_i)(\rho + \delta_i)}{1 - u} - \delta_i \tag{22}$$

and the overall gross rate of return to R&D capital is determined by a weighted average:

$$r_A^g = \sum_i S_i r_i^g. \tag{23}$$

The EMTR is then determined as above as $\tau_A \equiv \frac{r_A^g - \rho}{r_A^g}$.

Unlike the approach advocated here, while the standard weighted average approach has the benefit of not requiring information about the R&D production function, it is based on a faulty representation of the process underlying R&D, both in terms of the aggregation function and the economic characteristics of the inputs used to produce R&D capital.[19]

The question then becomes, does it make any difference? Do these alternative approaches produce markedly different calculations of the user cost and EMTR of intangible R&D capital? This question is addressed in the next section where some illustrative calculations are provided for both approaches.

3 An illustration: EMTR's on R&D capital in Canadian provinces

In this section, the methodology is applied to the determination of the user cost, and EMTR, of intangible R&D capital in Canadian provinces. Canada is somewhat unique in the sense that both the federal government and each of the provinces impose their own tax incentives for R&D.[20] It is generally recognized that Canada has one of the most generous tax treatments of R&D inputs in the world.[21] For some details on the system, see Appendix 2.

While the model developed above included only two inputs into the production of intangible R&D capital, in the empirical implementation five inputs are included:

[19] A natural question is whether there is any production function which implies that the standard weighted average approach is correct. I have not been able to establish whether or not there is such a function. The most obvious candidate is the FP production function, but, as shown below, it generates significantly different results than the weighted average approach. The reason comes down to the fundamental difference between the two aggregation approaches—the treatment of expenditures on labor and capital as inputs into the production of intangible R&D capital (knowledge) versus their treatment as intangible R&D capital in and of themselves.

[20] In the U.S. individual states also provide their own R&D incentives over and above the federal incentives. For an analysis of the impact of state R&D tax subsidies, see Wilson (2005).

[21] See Department of Finance (1998).

three current inputs (labor, contract R&D, and materials) and two capital inputs (equipment and buildings); each type of input receives different tax treatment. The EMTRs on each of the R&D inputs, the resulting EMTRs on R&D costs, and the associated tax wedges and EMTRs for intangible R&D capital, are reported for each province in Table 2.

The first five rows in the table present the EMTRs on the individual inputs into the R&D production process. Note that these EMTRs are negative for labor, contract R&D, materials and equipment used to produce intangible R&D capital in all of the provinces. Thus, the tax system in Canada subsidizes expenditures on these inputs into the R&D process. The high positive EMTR on buildings used in the production of intangible R&D capital reflects the fact that expenditures on buildings used in R&D are not eligible for any incentives or special treatment.

The EMTRs on the individual inputs used to produce intangible R&D capital are aggregated into the EMTR on R&D costs in the sixth and seventh rows of the table. Calculations are presented for two R&D production functions, a Cobb–Douglas (CD) function where the elasticity of substitution is unity, and a fixed-proportions (FP) function where the elasticity of substitution is zero. Noteworthy here is the fact that while the tax subsidies are slightly higher for the CD function than for the FP function, the EMTR on R&D costs is not very sensitive to the elasticity of substitution. Other calculations with different elasticities of substitution confirm this. Thus, at least within the class of CES R&D production functions, the assumption regarding the elasticity of substitution appears to be relatively innocuous. The EMTR on R&D costs is negative for each province, indicating the presence of an overall subsidy whereby the tax system lowers the marginal cost of producing intangible R&D capital. Note that there is substantial variation between the provinces in the EMTR on R&D costs, with the tax induced reduction in the marginal cost of producing R&D capital ranging from about 12% (in Prince Edward Island) to 30% (in Quebec).

Our primary interest, however, lies with the user cost, or the EMTR, for intangible R&D capital. Calculations of both the tax wedge and the EMTR on R&D capital are presented for the aggregation methodology developed above (for both the CD and FP functions) and for the standard approach whereby each input into the production of R&D capital is treated as R&D capital in and of itself, and a weighted average taken. The calculations for the approach developed above indicate that R&D capital is substantially subsidized in Canada, with the tax wedge on R&D ranging from about negative 2 percentage points in Prince Edward Island to negative 5.5 percentage points in Quebec.[22] This is a substantial subsidy to say the least, and are reflected in EMTRs on R&D capital that range from −33% to over −200%.

The standard weighted average approach also indicates the presence of a substantial subsidy, but at a much higher level—the tax wedges and the EMTR on R&D capital are much more negative. For example, under the standard approach the gross-of-tax rate of return on R&D in Ontario is 6.7 percentage points lower than the net-of-tax rate of return, while under the methodology proposed above the difference is just over 4 percentage points. Thus, in this case, the standard approach yields a subsidy wedge that is 60% higher (more negative) than that suggested by the proposed methodology.

[22] Neither Prince Edward Island nor Alberta offer any provincial incentives for R&D.

Table 2 Effective tax rate calculations for Canadian provinces, percent

	Alberta	British Columbia	Saskatchewan	Manitoba	Ontario	Quebec	New Brunswick	Nova Scotia	Prince Edward Island	Newfoundland
Effective marginal tax rates on R&D inputs										
Labor	−13.0	−22.5	−28.0	−27.0	−18.8	−30.4	−27.8	−27.5	−10.7	−25.8
Materials	−19.2	−29.3	−34.3	−34.3	−26.7	−19.2	−34.3	−34.3	−19.2	−34.3
Contract R&D	−13.0	−22.5	−28.0	−27.0	−41.2	−53.6	−27.8	−27.5	−10.7	−25.8
Equipment	−23.7	−33.2	−36.6	−36.9	−29.9	−22.4	−37.3	−37.4	−23.7	−38.0
Buildings	37.6	41.0	39.0	48.0	40.4	37.3	42.1	47.3	31.2	27.6
Effective marginal tax rates on R&D costs										
Cobb–Douglas	−13.2	−22.5	−27.8	−26.9	−24.3	−30.7	−27.6	−27.2	−11.9	−26.7
Fixed proportions	−12.5	−21.6	−26.7	−25.6	−22.9	−28.4	−26.4	−25.9	−11.4	−25.9
Tax wedges										
Cobb–Douglas	−2.4	−4.2	−5.1	−5.0	−4.5	−5.7	−5.1	−5.0	−2.2	−4.9
Fixed proportions	−2.3	−4.0	−4.9	−4.7	−4.2	−5.3	−4.9	−4.8	−2.1	−4.8
Wtd. average approach	−4.4	−6.2	−7.2	−7.0	−6.7	−8.6	−7.1	−7.0	−4.1	−6.9
Effective marginal tax rates on intangible R&D capital										
Cobb–Douglas	−40.3	−96.6	−153.5	−142.0	−112.7	−202.0	−151.0	−146.2	−35.0	−139.5
Fixed proportions	−37.6	−88.7	−139.1	−126.4	−99.3	−163.1	−136.0	−130.2	−32.9	−129.4
Wtd. average approach	−109.9	−269.5	−560.0	−462.8	−376.1	na[a]	−537.3	−496.1	−92.8	−435.8

[a] The EMTR on R&D capital under the weighted average approach is not defined for Quebec because the gross-of-tax rate of return (r^g) is negative in this case

This is a substantial difference, and is reflected in the exceedingly high (negative) EMTRs for intangible R&D capital calculated under the traditional methodology, which are three to four times higher (more negative) than under the approach advocated here.

While the weighted average approach typically used in the literature for intangible R&D capital overstates the size of the tax subsidy relative to the aggregation approach developed here, it is not clear whether or not this type of measurement error is a problem for econometric studies, as the “height” difference between the two approaches would be captured by the constant term of any regression. However, while the two measures are highly correlated in the example presented here (Canadian provinces), this is due in part to the use of common factor shares. In other contexts, where the factor shares may differ across jurisdictions, the covariance will not be as high.

4 Summary and conclusions

This paper develops a methodology for measuring the tax adjusted user cost of capital and the effective marginal tax rate (EMTR) on intangible R&D capital, in the tradition of Hall–Jorgenson–King–Fullerton (HJKF). Intangible R&D capital is modeled as a ‘non-marketed’ input produced in-house using other ‘marketed’ inputs. The contribution of this paper is to show how the true user cost and EMTR of intangible R&D capital can be constructed via an aggregation function based on the R&D production function. The paper therefore shows how the HJKF approach can be applied to intangible R&D capital in a way that is consistent with its microeconomic foundations.

The approach developed here allows diverse tax incentives across jurisdictions to be measured and compared in a way that is consistent with the microeconomic foundations of R&D. As an illustration, the methodology is applied to the measurement of tax incentives offered for R&D in Canadian provinces. It is shown that relative to the methodology developed here the standard approach to measuring the cost of R&D capital significantly overstates the size of the tax subsidy offered to R&D.

Several extensions and applications of the methodology developed here are possible. The approach may be used to determine effective marginal tax rates on R&D in other jurisdictions, allowing for a meaningful comparison of tax incentives across countries and regions. While the emphasis in this paper is on R&D, the general approach may also be applied to any input produced in-house. One example is expenditures related to advertising and marketing and the creation of “goodwill”; another involves the tax treatment of exploration and development in the resource sector. Also, an obvious next step would be to use the measure developed here in empirical work investigating the impact of R&D tax incentives. Finally, more work, both theoretical and empirical, regarding the in-house “production process” underlying R&D will lead to more refined measures of the impact of tax incentives.

Appendix 1: Derivation of (13)

By definition, the minimized cost of producing R&D is:

$$
\begin{aligned}
&C\big(G; w(1+T_L), q(\rho+\delta_A)(1+T_K)\big)\\
&\quad = w(1+T_L)L\big(G; w(1+T_L), q(\rho+\delta_K)(1+T_K)\big)\\
&\qquad + q(\rho+\delta_K)K\big(G; w(1+T_L), q(\rho+\delta_K)(1+T_K)\big),
\end{aligned}
\tag{24}
$$

where $L(G;\cdot)$ and $K(G;\cdot)$ are the conditional R&D input demand functions.

Therefore, we may write:

$$
\begin{aligned}
&MC\big(G; w(1+T_L), q(\rho+\delta_A)(1+T_K)\big)\\
&\quad \equiv \frac{\partial C(G; w(1+T_L), q(\rho+\delta_A)(1+T_K))}{\partial G}\\
&\quad = w(1+T_L)\frac{\partial L(G; w(1+T_L), q(\rho+\delta_K)(1+T_K))}{\partial G}\\
&\qquad + q(\rho+\delta_K)(1+T_K)\frac{\partial K(G; w(1+T_L), q(\rho+\delta_K)(1+T_K))}{\partial G}.
\end{aligned}
\tag{25}
$$

The partial derivatives of the conditional input demand functions are homogeneous of degree zero in the input prices, which means each R&D input price can be divided by $(1-u)$ without changing anything. Thus, for labor:

$$
\begin{aligned}
&\frac{\partial L(G; w(1+T_L), q(\rho+\delta_K)(1+T_K))}{\partial G}\\
&\quad = \frac{\partial L(G; w(1+T_L)/(1-u), q(\rho+\delta_K)(1+T_K)/(1-u))}{\partial G}
\end{aligned}
\tag{26}
$$

and similarly for capital:

$$
\begin{aligned}
&\frac{\partial K(G; w(1+T_L), q(\rho+\delta_K)(1+T_K))}{\partial G}\\
&\quad = \frac{\partial K(G; w(1+T_L)/(1-u), q(\rho+\delta_K)(1+T_K)/(1-u))}{\partial G}.
\end{aligned}
\tag{27}
$$

Now define the effective marginal tax rates (EMTRs) on R&D labor and capital respectively (τ_L and τ_K) as:

$$
\tau_L \equiv \frac{w(1+T_L)/(1-u) - w}{w} = \frac{1+T_L}{1-u} - 1,
\tag{28}
$$

$$
\tau_K \equiv \frac{q(\rho+\delta_K)(1+T_L)/(1-u) - q(\rho+\delta_K)}{q(\rho+\delta_K)} = \frac{1+T_K}{1-u} - 1.
\tag{29}
$$

Therefore (26) and (27) can be written as,

$$\frac{\partial L(G; w(1+T_L), q(\rho+\delta_K)(1+T_K))}{\partial G} = \frac{\partial L(G; w(1+\tau_L), q(\rho+\delta_K)(1+\tau_K))}{\partial G}, \tag{30}$$

$$\frac{\partial K(G; w(1+T_L), q(\rho+\delta_K)(1+T_K))}{\partial G} = \frac{\partial K(G; w(1+\tau_L), q(\rho+\delta_K)(1+\tau_K))}{\partial G}, \tag{31}$$

where for labor the distinction between $(1+T_L)$ and $(1+\tau_L)$ should be noted; and similarly for capital.

Using (30) and (31), (25) can be written

$$\begin{aligned} &MC\big(G; w(1+T_L), q(\rho+\delta_A)(1+T_K)\big) \\ &\quad = w(1+T_L)\frac{\partial L(G; w(1+\tau_L), q(\rho+\delta_K)(1+\tau_K))}{\partial G} \\ &\qquad + q(\rho+\delta_K)(1+T_K)\frac{\partial K(G; w(1+T_L), q(\rho+\delta_K)(1+T_K))}{\partial G}. \end{aligned} \tag{32}$$

Dividing both sides by $(1-u)$ it follows that:

$$\begin{aligned} &\frac{MC(G; w(1+T_L), q(\rho+\delta_A)(1+T_K))}{1-u} \\ &\quad = \frac{w(1+T_L)}{1-u}\frac{\partial L(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K))}{\partial G} \\ &\qquad + \frac{q(\rho+\delta_A)(1+T_K)}{1-u}\frac{\partial K(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K))}{\partial G} \end{aligned} \tag{33}$$

or, using the definition of the EMTRs,

$$\begin{aligned} &\frac{MC(G; w(1+T_L), q(\rho+\delta_A)(1+T_K))}{1-u} \\ &\quad = w(1+\tau_L)\frac{\partial L(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K))}{\partial G} \\ &\qquad + q(\rho+\delta_A)(1+\tau_K)\frac{\partial K(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K))}{\partial G} \\ &\quad = \frac{\partial C(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K))}{\partial G} \\ &\quad = MC\big(G; w(1+\tau_L), q(\rho+\delta_A)(1+\tau_K)\big). \end{aligned} \tag{34}$$

Appendix 2: The tax treatment of R&D in Canada

The federal government and all of the provinces allow the immediate expensing of current expenditures (labor and materials) employed in the R&D process. This immediate write-off is extended to machinery and equipment. The province of Ontario (the largest province in the country) allows a "super allowance" of 25% on top of this, increasing the write-off rate to 125% for provincial corporate income tax purposes.

Aside from the fast write-off of some of the expenditures used in the production of R&D, the federal government provides a 20% non-incremental tax credit for expenditures on labor, materials and equipment (but not buildings) used in the production of R&D. Most (but notably not all) provinces piggy back on the federal credit with their own R&D credit, typically of 10 or 15%.

The federal government imposes a statutory corporate income tax (CIT) rate of 22.12%, and the provincial CIT rates for the manufacturing sector vary from 5 to 15.5%, depending on the province. Moreover, some of the provinces impose explicit capital taxes on equipment and buildings. Payroll, income and sales taxes imposed on labor also differ across provinces. It is assumed, following Dahlby (1996), that firms bear one-third of the burden of taxes imposed on labor.

The following equations for the after-tax cost of a one dollar R&D input expenditure apply to the Canadian tax system. Some of the provinces may deviate slightly from the general formulas presented below due to specific provisions.

For labor and contract R&D:

$$1 + T_L = (1 + t_{L\mathrm{f}} + t_{L\mathrm{p}})(1 - u_\mathrm{f} - u_\mathrm{p})(1 - \phi_\mathrm{f} - \phi_\mathrm{p}).$$

For materials:

$$1 + T_M = (1 + t_\mathrm{sp})(1 - u_\mathrm{f} - u_\mathrm{p})(1 - \phi_\mathrm{f} - \phi_\mathrm{p}).$$

For depreciable capital:

$$(1 + T_K) = (1 + t_\mathrm{sp})(1 - \phi_\mathrm{f} - \phi_\mathrm{p})(1 - u_\mathrm{f} - u_\mathrm{p})Z + \big(t_\mathrm{kp}(1 - u_\mathrm{f} - u_\mathrm{p})\big)(1 - \phi_\mathrm{f} - \phi_\mathrm{p})/(\rho + \delta_\mathrm{k}).$$

The parameter u_f is the federal CIT rate and u_p is the provincial rate, ϕ_f is the federal R&D tax credit rate and ϕ_p is the provincial rate, $t_{L\mathrm{f}}$ is the effective federal tax rate on labor and $t_{L\mathrm{p}}$ is the effective provincial rate, t_sp is the indirect sales tax on materials and capital arising from provincial sales taxes, Z is the present value of tax depreciation allowances, t_kp is the provincial capital tax rate, and δ_k is the economic depreciation rate on physical capital used in the production of R&D.

Table 3 presents the tax parameters underlying the EMTR calculations in Table 2. More details are available on request. Bigrler data and parameter assumptions are:

1. The federal R&D tax credit is 20% for all provinces.
2. The present value of the tax depreciation deductions is .95 for equipment and .26 for buildings in all provinces.
3. The nominal interest rate is 10%.
4. The inflation rate is 3%.
5. The economic depreciation rate on R&D equipment is 18%.
6. The economic depreciation rate on R&D buildings is 3.7%.
7. The economic depreciation rate on intangible R&D capital is 10%.
8. The factor shares used to calculate the EMTR on R&D costs are: 45% labor, 25% materials, 20% contract, 5% equipment, 5% buildings.

Table 3 Key tax parameters, Canadian provinces, 2003, percent

	Alberta	British Columbia	Saskatchewan	Manitoba	Ontario	Quebec	New Brunswick	Nova Scotia	Prince Edward Island	Newfoundland
Combined federal–provincial CIT rate on manufacturing	33.62	35.62	32.12	37.62	34.12	31.02	35.12	38.12	29.62	27.12
Provincial R&D tax credit	0	10	15	15	0[a]	0[b]	15	15	0	15
Capital tax rate	0	0	0.60	0.50	0.30	0.60	0.30	0.25	0	0
Effective labor tax rate on business[c]	8.78	10.72	10.73	12.25	11.78	16.08	11.05	11.60	11.66	14.17

[a]Ontario does not have an R&D tax credit, but grants a 25% super allowance on R&D expenditures

[b]In Quebec a special R&D Tax Credit of 40% applies to contract R&D

[c]Includes personal income tax, payroll tax, and sales/excise tax. Assumes that businesses bear 30% of the burden of these taxes (the figures in the table are businesses share)

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