A cost-benefit analysis of R&D tax incentives

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Abstract. Although technical knowledge generates spillover benefits, production of technical knowledge creates congestion externalities; thus, private R&D investment could be inefficient. A computable general equilibrium model is used to rank tax incentives by their effects on research effort and measure welfare effects. Five results stand out: R&D tax credits produce relatively large increases in research effort and welfare. Lower corporate income tax rates and ITCs for downstream users of high-tech production inputs rank second. Revenue losses from lower personal income tax rates can produce welfare losses. Ironically, ITCs for upstream producers of innovative inputs are ineffective. Incremental R&D credits dominate comprehensive credits. JEL Classification: E62, H21, O38

Une analyse coûts avantages des incitations fiscales à investir dans la R&D. Même si la connaissance technique engendre des effets de retombée, la production de connaissance technique crée aussi des effets externes de congestion. Voilà qui suggère que l’investissement privé en R&D peut être inefficace. Ce mémoire utilise un modèle d’équilibre général calculable pour ordonner les incitatifs fiscaux selon leurs effets sur l’effort de recherche et pour en mesurer les effets de bien-être. On note cinq résultats : (1) les crédits d’impôt pour la R&D entraînent des accroissements importants dans l’effort de recherche et dans le niveau de bien-être; (2) les taux d’imposition plus bas sur les revenus des sociétés et les crédits d’impôt pour l’investissement des utilisateurs d’intrants de haute technologie en aval se classent au deuxième rang; (3) les pertes de revenu attribuables à des taux d’imposition plus bas sur les revenus des personnes peuvent engendrer des pertes de bien-être; (4) ironiquement, les crédits d’impôt pour l’investissement des producteurs

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d'intrants innovateurs en amont sont inefficaces; (5) des crédits d'impôt additionnels sur la R&D sont préférables à des crédits compréhensifs.

1. Introduction

R&D investors often fail to account for losses they impose on previous innovators, as well as social costs of duplicated research effort: this suggests privately financed R&D investment could be too high (Aghion and Howitt 1992; Jones and Williams 2000). But R&D investors also fail to account for intertemporal knowledge spillovers and consumer surplus they create: this suggests privately financed R&D investment could be too low (Romer 1990; Grossman and Helpman 1991).1 Jones and Williams (1998, 2000) derive a functional relationship between the social returns to R&D and private R&D investment. Their results suggest that the large social returns reported in the empirical literature (Griliches 1992) are lower bounds, and that net social gains of private R&D are relatively high.2

Tax policy has a potential to improve social welfare by encouraging R&D investment. All too often, however, gains from development policies fall short of promises. The Canadian federal government as well as most provinces, many OECD countries, and the U.S. federal government as well as many states provide R&D incentives. Policy makers appear to assume that more R&D is socially preferable to less. A second apparent, and potentially more costly, assumption is that tax incentives do, in fact, stimulate research effort. Policy decisions should be based on firmer ground.

Economists have responded to this challenge with a series of empirical contributions reporting measurements of the effectiveness of R&D tax credits. Authors of some studies fail to find statistically significant evidence that tax credits increase R&D (U.S. GAO 1996; Goolsbee 1998; and Billings, Glazunov, and Houston 2001), while others find such evidence (Mamuneas and Nadiri 1995; Hall and Van Reenan 1999; and Bloom, Griffith, and Van Reenan 2002). (Hall and Van Reenan Review empirical evidence.) However, empirical analysis of R&D incentives faces high hurdles. Hall and Van Reenan (1999) argue that the theoretical justification for empirical specifications often is unclear. The U.S. General Accounting Office (GAO, 1996) criticizes firm level studies for failing to use actual tax return data.3 Legislated changes in taxes often are accompanied by changes in tax structure that affect agents’ behavioural responses to taxes, or

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1 Credit market failure also reduces R&D (Stiglitz 1993; Hall 1992; Aghion and Howitt 1998; and Hall 2002).

2 Griliches (1973) uses growth accounting in a neoclassical framework to calculate Total Factor Productivity growth. The coefficient in a regression of TFP on the R&D/GDP ratio provides an estimate of the social return to R&D. Jones and Williams (1998) show how to estimate social rates of return under endogenous innovation.

3 The U.S. GAO (1989) compares tax return data with publicly available data, judging the latter to be an unsatisfactory proxy. Public data measure taxable income and R&D differently than does the IRS.
that change the definition of taxable income. Empirical studies use short-run data to study short-run relationships (Goosbee 1998, 2003). Short-run elasticities tend to be smaller than long-run elasticities. This applies particularly to the supply of skilled workers, because human capital accumulates only very slowly. Since short-run labour supply is relatively inelastic, incentives may drive up wages in the short run, reducing the short-run efficacy of the incentives (Goosbee). General equilibrium relationships could differ greatly from partial responses. The long-run, general equilibrium, relationships are required for understanding welfare effects.

Social costs of R&D tax incentives lie in wasted resources and distortions created by financing incentives: social benefits lie in technical knowledge spillovers and new consumer surplus created by otherwise unrealized innovations. Individual researchers do not take these wider costs and benefits into account in making investment decisions; thus, the relationships between R&D tax credits, and social costs and benefits, are difficult to capture empirically. For example, the ratio of the change in private R&D spending to R&D tax expenditures often is used to measure effectiveness of R&D policy. However, the social value of non-rival technical knowledge can exceed tax expenditures even while R&D spending falls short of tax expenditures.

Computable General Equilibrium (CGE) models provide tools to overcome some of the measurement hurdles. For example, computer models can be used to measure knowledge spillovers and external costs. The external costs and benefits affect lifetime consumption, so their values are captured by simulation of the lifetime utility function.

Recent CGE models incorporate endogenous innovation. This is important for three reasons. First, there is no reason to expect R&D incentives will work, unless innovation is endogenously chosen. Second, endogenous innovation makes the economy much more responsive to taxes than it otherwise would be. Third, endogenous innovation is useful in capturing social costs and benefits missed by empirical studies, for example knowledge spillovers. Concerning the second reason mentioned above, note that endogenous innovation and saving are complementary: since innovation is endogenous,

4 See Triest (1998) and Slemrod (1998) for discussions of econometric problems that result from the interaction between tax rates and taxable income, more generally, in studies of the behavioural effects of taxes.
5 Goosbee’s (2003) estimates indicate wages in capital goods industries rose 20–40% of the U.S. ITC for physical capital. The larger the effect on wages, ceteris paribus, the smaller the effect on real investment. However, higher wages themselves could stimulate more intense work effort, so the offset in research effort may be smaller than 20–40%.
6 See section 8.5 in Aghion and Howitt (1998) for discussion of measurement problems non-rival innovations create. See section 3.2, below, for criticism of the most common method used to measure effectiveness of R&D tax incentives.
7 Arrow’s (1962) Learning-by-Doing is the intellectual precursor to modern versions of knowledge spillovers. With Learning-by-Doing, spillovers are exogenous side-effects of production. When innovation is endogenous, spillovers increase profits, increasing the incentive to innovate and the standard of living.
a saving-induced decline in the discount rate on profits encourages faster innovation: since saving is endogenous, faster innovation stimulates saving (by increasing productivity of private resources). Lin and Russo (2002) use a CGE model to quantify this complementary relationship. Complementarity plays a sizeable role in the economy's response to taxation.

Diao, Roe, and Yeldan (1999) construct a CGE model with endogenous innovation. They study direct R&D subsidies, subsidies to capital, and trade policy. Their results indicate that direct subsidies produce relatively large increases in welfare. Capital subsidies rank second. Trade policies have the smallest effect and could reduce welfare. Ghosh (2003) uses a model similar to Diao, Roe, and Yeldan, parameterizing the model to reflect Canada's economy. The goals, methods, and models, in Diao et al., Ghosh, and the current paper differ in many important respects. However, the results are consistent, and the differences in the approaches make them complementary.

In this paper a CGE model is used to rank R&D incentives by their effects on research effort. The associated welfare effects also are reported. Many observers and policy makers suggest that lower corporate and or personal income tax rates would stimulate R&D and growth, so these taxes are studied here. Romer (1990) and Grossman and Helpman (1991) argue that physical capital subsidies may be ineffective. This ironic conjecture is 'tested' here. The Investment Tax Credit (ITC) targeted on R&D is also examined. Five results stand out. (1) Incremental and comprehensive R&D tax credits produce relatively large increases in research effort and welfare. (2) Lower corporate income tax rates, and ITCs for downstream users of innovative inputs, rank second and third. (3) Revenue losses from lower personal income tax rates can produce welfare losses. (4) ITCs for upstream producers of innovative goods are ineffective. (5) Incremental R&D credits dominate comprehensive credits.

In section 2 the simulation model and tax treatment are briefly described. In section 3 cost-effectiveness, a measure commonly used to gauge the efficacy of R&D tax incentives, is reviewed and critiqued. In section 4 long-run changes in research effort are simulated and used to rank tax incentives, and welfare measurements are reported; sensitivity analysis is also reported, and the efficacy of comprehensive and incremental tax credits is compared. Section 5 concludes.

8 In the current paper we study a closed economy. Coe and Helpman (1995) provide evidence that foreign R&D has a larger effect on productivity, the larger a country's import/GDP ratio. R&D incentives could be more effective in small open economies, since domestic R&D improves the ability to benefit from foreign R&D.

9 Diao et al. finance incentives with lump-sum taxes. Ghosh finances incentives with higher sales taxes. Here, we finance incentives by decreasing government infrastructure spending. Also, those authors use Romer's (1990) knowledge production function, with Constant Returns to Scale and no congestion externality: they hold the physical capital stock and the labour force constant, to avoid scale effects. The model in this paper uses Jones's (1995) production function for technology, which eliminates scale effects by incorporating duplicated research effort and diminishing marginal returns.
2. The Simulation model and tax structure

2.1. The model
The simulation model used in this paper is based on Romer (1990) and Jones (1995). Romer introduced the model of endogenous innovation. The two fundamental premises here are (1) technical knowledge is non-rival, and (2) R&D investment is motivated by monopoly profits. Since technical knowledge is non-rival, future skilled workers use it to create additional innovations. Innovative firms secure patents to exclude other firms from appropriating the returns to their innovations. In Romer’s model, spillovers from non-rival knowledge are sufficiently productive to generate scale effects; that is, the long-run growth rate accelerates as stocks of human and physical capital grow. However, Jones produced empirical evidence indicating an absence of scale effects. He shows how to eliminate the effects of scale by including diminishing marginal returns in the production of knowledge, and duplication of skilled workers’ research efforts. Jones’s approach is used in this paper to eliminate scale effects. Appendix B shows how this approach is implemented here.

Three sectors are included in the current version of the Romer/Jones endogenous innovation model: a household sector that chooses how much to consume, save, and work, in order to maximize lifetime utility; a business sector that chooses quantities of resources to employ and output to produce, in order to maximize profits; and a government sector that collects taxes, issues patents, and purchases infrastructure (airports, roads and bridges, etc.). The business sector includes two types of firms: upstream innovative firms hire skilled labour to conduct research, producing innovative inputs to sell to downstream final goods firms; downstream final goods firms hire skilled labour and the innovative inputs to produce output. The market for innovation is imperfectly competitive. The markets for final goods, capital, and labour are perfectly competitive.

Of the modelling elements described above, all but two are standard in endogenous innovation models. The non-standard elements are endogenous labour supply and government infrastructure spending. Endogenous labour supply is included here because it responds (with small elasticity) to wage rates. Labour supply response could affect, and be affected by, the economy’s response to R&D incentives.

A number of considerations argue for including endogenous government infrastructure in long-run models used in fiscal policy analysis. The most obvious consideration is that the government’s long run intertemporal budget constraint implies that tax revenue and government spending must grow at equal rates in the long run. This budget requirement could be satisfied even if government spending has no real effects, so budget balance does not dictate that tax incentives be financed by adjustments in infrastructure spending. However, government infrastructure could have real effects, altering the productivity of private capital. In this case, government infrastructure and tax revenue must grow at equal rates in the long run. To see this, note that
infrastructure, such as a new road in an uncongested area, is somewhat non-rival: under ideal conditions the marginal cost of providing service to an additional user is near-zero. If infrastructure grows more slowly than the private economy, however, additional users eventually impose congestion costs on others, potentially reducing productivity of private resources. To attain balanced long-run growth, therefore, the external benefit of non-rivalry must just offset the external cost of congestion. The two effects offset only if infrastructure grows at the same rate as the rest of the economy (Barro and Sala-i-Martin 1999). Since tax revenue grows at the economy-wide growth rate in the long run, infrastructure also must grow at that rate. To satisfy this constraint in this paper, government infrastructure is adjusted endogenously to the prevailing level of tax revenue.

Except for endogenous labour supply and government infrastructure, the complete model is described in Lin and Russo (2002). See appendix A, below, for an explanation of how their model is altered by including these two elements. The augmented simulation model includes nine endogenous variables and nine equations. Mathematica software is used to conduct the simulations. Note that derivation of quantitative measurements from the computer model is complicated by the fact that the model's solution requires variables measured in effective labour units. However, in order to interpret welfare effects of tax-induced changes in the level of technology, variables should be measured in per capita units. Transformation from effective labour units to per capita units is difficult because the computer model does not use or produce a measure of the level of technology. It is shown in appendix B how the output of the computer simulations, measured in effective labour units, is transformed into per capita units.

2.2. R&D and tax structure
The definition of R&D used by the Canadian government generally is consistent with the concept used by the Organization for Economic Cooperation and Development. R&D refers to activity designed to increase the stock of knowledge or to devise new applications of knowledge. R&D activity includes basic research, designed to advance scientific knowledge without regard to specific practical applications; applied research, designed to advance knowledge of specific practical applications; and experimental development, designed to create or improve materials, devices, products, or processes. R&D spending includes salaries or wages, cost of materials, lease costs relating to machinery and equipment used 90% or more in Canada, and contract R&D. R&D spending in Canada can be expensed. Unused deductions can be carried

10 The augmented model is available on request.
11 The list includes quantities of consumption, physical capital, labour, research effort, and government infrastructure spending; also prices of innovative inputs, patents, skilled labour, and capital services.
forward indefinitely. The statutory credit rates are 20% and 35%, respectively, for larger and smaller Canadian-controlled corporations. R&D also is eligible for a tax credit.\(^{12}\) However, R&D expensible in a year is reduced by the amount used to calculate the prior year’s credit. Unused credits can be carried back three years, and forward 10 years.\(^{13}\)

The U.S. tax code defines R&D as activity intended to discover information that would eliminate uncertainty regarding the development or improvement of any pilot model, process, formula, invention, technique, patent, or similar property, used by the taxpayer in trade or business, or for sale, lease, or license. R&D spending includes costs of securing patents, wages, supplies, costs of non-depreciable property, payments for the ‘right’ to use computers, 65% of contract research, and payments to organizations such as universities. U.S. firms can expense R&D spending or they can take an R&D tax credit. Unused credits can be carried back three years and forward 15 years. The statutory credit rate is 20% of qualified costs in excess of a ‘base amount’.\(^ {14}\)

An important difference between the Canadian and U.S. tax credits is that the former is comprehensive, applying to almost all R&D spending, while the latter is incremental, applying only to the amount above the base amount.\(^ {15}\) The simulations compare the effects of incremental and comprehensive credits.

Unless otherwise noted, the computer experiments assume that government infrastructure spending adjusts to maintain budget balance each period. Infrastructure is financed by taxes. Household and unincorporated business income are subject to a proportional personal income tax. Unincorporated business deducts wages and debt service from gross receipts. The model assumes 20% of final goods production is subject to the personal income tax. The corporate income tax is assessed on the remainder. Innovative producers pay the corporate income tax, which is a proportional levy on revenue net of wages, debt service, depreciation and amortization, and R&D spending. Corporate and unincorporated businesses receive an ITC on purchases of capital goods. ITCs for physical capital tend to be narrowly targeted on machinery and equipment, so the ITC is restricted to 10% of physical capital. The simulations assume this ITC is taken by innovative firms, for their physical capital purchases (\(ITC_X\)), and, separately, by final goods producers, for renting innovative inputs (\(ITC_Y\)). These ITCs initially are set equal to 10%. Innovative firms also receive an ITC for R&D spending (\(ITC_{RD}\)). Hall (1993, table 3) estimated the U.S. marginal effective rate for the \(ITC_{RD}\) at about 7.7% in 1990, so this value is used. The

\(^{12}\) However, the credit rate for equipment that is used mostly in Canada is one-half the normal rate.

\(^{13}\) For details of Canada’s treatment of R&D, see Department of Finance Canada (1997a,b). In Canada, R&D eligible for special tax treatment often is denoted SR&ED (Scientific Research and Experimental Development).


\(^{15}\) Canada used an incremental credit in the early 1980s.
corporate income tax rate initially is set equal to 35%. The personal income tax rate initially is set equal to 21%. Sensitivity analysis shows these initial tax rate settings do not affect the simulation results. Except for the ITC for physical capital, which was eliminated by the U.S. Tax Reform Act of 1986, the simulations are based primarily on the U.S. federal tax structure.

3. Cost-effectiveness

3.1. Measuring cost-effectiveness
Cost-effectiveness, measured as the ratio of additional private R&D spending to government tax expenditure, or as the tax incentive elasticity of R&D spending, often is used to quantify the impact of R&D incentives. Mansfield and Switzer (1985a,b) report on surveys indicating the cost-effectiveness of Canada’s R&D tax credit was between 0.3 and 0.4 in the 1980s. The U.S. GAO (1989) reports cost-effectiveness of the early version of the U.S. ITC for R&D at about 0.4, and Swenson (1992) reported an estimate of about 0.3. Hall’s (1993) empirical estimates, using U.S. data through 1991, imply a value of about 2.0. The Department of Finance’s (1997a) survey indicates cost-effectiveness of the currently more generous Canadian R&D tax incentives at 1.4. Hines’s (1993) analysis of R&D expensing by U.S. multinationals suggests cost-effectiveness of this tax incentive is between 1.2 and 1.8.

Cost-effectiveness of $ITC_{RD}$ can be computed for the current model by exploiting the first order condition for skilled labour employed in research:\textsuperscript{16}

$$\tilde{w} = \frac{1 - \tau^A}{1 - ITC_{RD}} \tilde{P}_{A|A}(\zeta h)^{-1}.$$  

(1)

$\tilde{w}$ is the wage rate earned by skilled workers, and the innovative firm’s before-tax research cost, per worker; $\tau^A$ is the corporate income tax rate; $ITC_{RD}$ is the ITC for R&D; $\tilde{P}_{A}$ is the price of patents; $g_A$ is the long-run growth rate of technical knowledge; and $h$ is the proportion of the labour force endowed with technical skill. Each of these variables is exogenous to the individual firm. However, individual innovative firms choose $\zeta$, the proportion of skilled labour to employ. $\zeta h$ measures research effort. R&D spending per worker is the product of $\zeta h$ and $\tilde{w}$. The right-hand side of equation (1) is the marginal return to skilled labour in research, adjusted for taxes. Everything else held constant, an increase in $ITC_{RD}$ would increase the post-tax marginal return to research, profit-maximizing innovators would increase demand for skilled labour, and $\zeta$ would increase. Holding constant $h$ and $\tilde{w}$, cost-effectiveness is

\textsuperscript{16} This is (B12) in Lin and Russo (2002), except $\tau^A$ is absent from the denominator of (1), since the current model imposes the statutory restriction that firms taking the credit cannot expense R&D, and the symbol $ITC_{RD}$ replaces $\gamma$. 

about 1.0 in this model: R&D spending increases about one dollar per dollar revenue forgone, before general equilibrium interactions in other variables and markets.

3.2. Evaluating cost-effectiveness
If forgone revenue exceeds incremental R&D spending, cost-effectiveness is less than unity. This outcome generally is treated as unsatisfactory. However, there are no necessary relationships between cost-effectiveness, research effort, and economic welfare. A tax incentive that increases R&D investment spending may not increase research effort if labour supply is inelastic, since higher spending could dissipate in higher wages (Goolsbee 1998).\textsuperscript{17} If cost externalities exist, welfare may not improve, even if research effort increases. Ceteris paribus, final consumption is the opportunity cost of resources employed in R&D. Welfare may not improve because research effort could dissipate in creative destruction (Aghion and Howitt 1992), wasting resources that could otherwise be used to increase consumption. Research effort is duplicated to some extent, so there is slippage in the relationship between research effort and innovation (Jones 1995; Jones and Williams 2000). R&D tax incentives may be financed by higher distortionary taxes, or lower spending elsewhere in the budget. If the forgone spending would have enhanced private productivity, welfare tends to decline. Cost-effectiveness does not account for these opportunity costs, so welfare could decline even if cost-effectiveness exceeds one.

On the other hand, cost-effectiveness could easily underestimate the value of R&D incentives. If a tax incentive increases the level of real resources employed in research, the level of innovation tends to rise. The positive technical knowledge spillovers that result and the consumer surplus gained are intangible and are not reflected in cost effectiveness. Cost effectiveness could measure less than one even while innovation and net welfare increase.

4. Simulated long-run effects of R&D incentives

4.1. Research effort and welfare measurement
The sections below rank R&D tax incentives according to research effort. Research effort is measured as the proportion of skilled labour employed in the innovative sector. The effects on welfare also are reported. Welfare is measured here by equivalent variation. Utility held constant, distorting taxes increase minimum expenditure. Defined in terms of the minimum expenditure function, equivalent variation is the maximum one would pay to avoid a tax. Equivalent

\textsuperscript{17} However, it is important to remember that higher wages tend to encourage research intensity. This may be particularly true in the case of R&D investment, where a large proportion of investment is work effort per se. Thus, higher wages are not a sure sign that subsidies are wasted.
TABLE 1
Effects of tax incentives on research effort, welfare, and R&D spending

<table>
<thead>
<tr>
<th>R&amp;D tax incentive</th>
<th>2 Post-reform credit or rate</th>
<th>3 Change in research effort</th>
<th>4 Equivalent variation</th>
<th>5 Change in R&amp;D spending</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $ITC_x$</td>
<td>31.6%</td>
<td>0.0%</td>
<td>-0.7%</td>
<td>0.3%</td>
</tr>
<tr>
<td>2. Personal income tax</td>
<td>19.8</td>
<td>0.1</td>
<td>0.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>3. $ITC_y$</td>
<td>17.0</td>
<td>0.4</td>
<td>-0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>4. Corporate income tax</td>
<td>34.5</td>
<td>0.9</td>
<td>-1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>5. $ITC_{RD}$</td>
<td>32.8</td>
<td>18.5</td>
<td>-17.6</td>
<td>18.5</td>
</tr>
</tbody>
</table>

NOTES: $ITC_x$ and $ITC_{RD}$ are ITCs innovative firms receive for physical capital and R&D spending, respectively; $ITC_y$ is the ITC final goods producers receive for input purchases; research effort is measured by the amount of skilled labour employed in research.

variations of distortionary taxes, therefore, must be positive. Since the R&D subsidies tend to improve welfare, most equivalent variations reported below are negative.

4.2. Effects of equal revenue changes in a tax credit or rate

Substantial amounts of time are necessary to accumulate physical and knowledge capital and for knowledge spillovers to occur. Therefore, the simulations solve for the long-run, balanced growth path, general equilibrium of the economy. The government’s budget is balanced in each simulation reported in this subsection. Tax incentives are introduced exogenously, and tax revenue and government infrastructure spending respond endogenously. Introduction of each new incentive is permanent and unanticipated by market participants. In each experiment, either a tax credit rate is increased, or an income tax rate is decreased. In each case, the introduction of the incentive is restricted to cost 1% of tax revenue.18

We use the model described in section 2 to conduct the basic experiments and record the results in table 1. The table shows incentives ranked by their effects on research effort, beginning with the weakest incentive in row 1. Column 2 shows the tax credit (rate) after an incentive is implemented. Since the tax credits have relatively small effects on revenue, they must be increased greatly to effect 1% revenue changes. Credits this large probably are politically infeasible. Since each tax incentive has the same initial revenue cost, the results represent stimulus per dollar of revenue forgone; therefore, the comparisons show relative effectiveness, or ‘bang-for-buck,’ measures of incentives.

18 I am grateful to Claude Lavoie for suggesting this approach.
4.2.1. $ITC_x$
Row 1 in table 1 shows the effects of increasing $ITC_x$, the tax credit that upstream, innovative firms receive for physical capital purchases. Column 3 shows that research effort is unaffected. This possibility is anticipated by Romer (1990) and Grossman and Helpman (1991). $ITC_x$ reduces the cost of physical capital used by innovative firms, increasing the value of innovations, the productivity of skilled labour used in innovation, and the wage rate for skilled labour employed by the innovative sector. These adjustments tend to draw skilled labour away from final goods production, into R&D, increasing research effort. However, $ITC_x$ also lowers the production cost of innovative inputs, lowering the production cost of final goods, increasing productivity of skilled labour in final goods, and the wage rate for skilled labour employed by the final goods sector. These adjustments tend to offset the impetus towards greater research effort. Romer says an exact offset is not a necessary result. The experiment indicates that this particular incentive is likely to cause competition for skilled labour that dissipates in higher wages, with little effect on research effort and the level of innovation.

Column 4 shows that welfare increases. This occurs because the credit lowers the cost of physical capital used to produce innovative goods, increasing the physical capital stock in the long run.

4.2.2. Personal income tax
The pre-personal tax interest rate determines the discount rate on expected future profits. The personal income tax discourages household saving, which increases the pre-tax interest rate, increasing the discount rate on profits and discouraging R&D investment. The personal income tax applies to unincorporated businesses. Since these firms cannot expense all their physical capital, the personal income tax discourages investment in physical capital by these firms, shrinking the market for innovative goods and discouraging R&D investment. Column 3, row 2 shows that reducing the personal income tax rate increases research effort by a small amount. This means that a reduction in the personal income tax would increase the rate of innovation and the level of productivity in the long run.

However, the positive sign in column 4 indicates that welfare declines by a small amount. Welfare falls, in this case, because (i) the decrease in the personal income tax has relatively large long-run revenue costs (Russo 2003), (ii) government infrastructure spending enters the final goods production function, and (iii) government infrastructure is endogenous in this model (since infrastructure adjusts to maintain budget balance). For the basic experiments shown in table 1, the infrastructure elasticity of final goods production is assumed to be 0.4. In this case, government infrastructure is a non-rival public good, with spillover benefits that increase the productivity of private resources. When the personal income tax rate is reduced, tax revenue falls considerably, so government infrastructure spending falls considerably, which reduces the
productivity of private resources, putting downward pressure on long-run consumption. In this particular case, the decrease in consumption is sufficient to offset the tendency towards higher consumption resulting from the fact that lower taxes encourage more saving.19

4.2.3. $ITC_y$
Row 3 shows the effect of increasing $ITC_y$, the tax credit that downstream final goods producers receive for purchasing inputs. Research effort increases 0.4%. The fixed costs of producing a new innovation are large, while the marginal cost of providing the innovation to an additional user is relatively small; thus, per unit profit increases with market size. $ITC_y$ increases the size of the market for innovative inputs, increasing profits and encouraging R&D investment.

Comparing the last result with the result in row 1 indicates, ironically, that the ITC for physical capital employed by downstream users of innovative inputs (say desktop computers) tends to stimulate R&D, while the ITC for physical capital employed by upstream producers of innovative inputs (say microprocessors) does not. The difference in results stems from the way each subsidy affects the relative productivity of labour in final goods production and in research. $ITC_x$ increases the productivity of labour in final goods production and in research by similar amounts. Thus, the allocation of skilled labour and research effort remain unchanged. In contrast, $ITC_y$ causes the value of patents to increase five times more (not shown in the tables) than the productivity of labour in final goods production. This increases the relative productivity of labour in research, causing a migration of skilled labour from the final goods sector to the innovative sector.

Column 4 indicates $ITC_y$ would increase welfare by an amount equivalent to increasing per capita consumption by 0.4%. However, this probably overstates the value of ITCs for machinery and equipment. $ITC_y$ distorts the allocation of investment among different types of equipment. Fullerton and Henderson (1989) find that the ITC for machinery and equipment can decrease welfare: the distortion among different types of physical capital can exceed the reduction in the distortion to the level of investment. A contributing factor here is the difference in the length of the economic lives of different types of capital. The model used here assumes the economic life of each is the same. In a more general model, welfare increases from $ITC_y$ would be smaller than indicated here.

4.2.4. Corporate income tax
Row 4 shows that reducing the corporate income tax rate increases research effort and net welfare by relatively large amounts. The corporate tax affects

19 The sensitivity analysis reduces the infrastructure elasticity of final goods to 0.0. In that case, the decrease in government infrastructure does not reduce private productivity, and welfare increases (column 3, table 2).
both the demand side of the market for innovative goods, by expanding the final goods sector, and the supply side, by increasing the post-corporate tax profit earned on innovative inputs.

4.2.5. ITC$_{RD}$
Row 5 shows that increasing the ITC for R&D increases research effort by 18.5% in this model. Since the credit increases with the amount of skilled workers employed in research, the effect on research effort is direct. Net welfare increases by 17.6%. ITC$_{RD}$ is capable of much larger stimulus than the other tax incentives, per dollar of revenue forgone. However, ITC$_{RD}$ must increase to 32.8%, from an initial value of 7.7%, in order to deliver a 1% change in revenue. The results must be interpreted cautiously. The correct interpretation is that it may be possible to provide a relatively large stimulus to R&D, at a relatively small revenue cost, via ITC$_{RD}$. The important point is that the impact of ITC$_{RD}$ far outweighs the impact of the other incentives, per initial dollar of revenue cost.

Before leaving this section, consider column 5, which shows the effects of incentives on R&D spending. In the case of ITC$_x$, R&D spending increases, although research effort is unchanged. The incentive is dissipated in higher wages for skilled labour. In contrast, the personal income tax cut reduces R&D spending, although research effort rises. This occurs because the wage rate declines in this case. However, in section 3.1 it was shown that the short-run – pre-general equilibrium response – measure of cost-effectiveness is unity in this model. These cases provide examples where cost-effectiveness produces misleading indications of the true, long-run efficacy of tax incentives.

4.3. Sensitivity analysis
For the Table 1 experiments, the government infrastructure elasticity of final goods production, $\varepsilon$, was set equal to 0.4. Aschauer's (1989) empirical estimates suggest this value. In this case, government infrastructure increases the productivity of private resources in final goods production. Since infrastructure varies to maintain budget balance, $\varepsilon$ could affect the results. Holtz-Eakin (1994) and Evans and Karras (1994) report empirical evidence suggesting $\varepsilon$ may be close to zero. Columns 2 and 3 in table 2 show the effects of R&D incentives when $\varepsilon$ is 0.0. Although absolute effects on research effort are larger than before, the ranking is preserved. Also note that the personal income tax reduction now increases welfare, in contrast to table 1. The difference here is that the decrease in government infrastructure, necessitated by lower income tax revenue, does not reduce the productivity of private resources, so the increase in saving and physical capital stock determine the long-run effect on consumption and welfare.

Labour supply is endogenous in this model. The wage elasticity of labour supply is controlled by the parameter $\eta$. The previous calculations assume $\eta=0.5$. Using the same form for utility used here, Jones, Manuelli, and
TABLE 2
Sensitivity to parameters

<table>
<thead>
<tr>
<th>R&amp;D incentive</th>
<th>( \varepsilon = 0.0 )</th>
<th>( \eta = 7.0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 Change in research effort</td>
<td>3 Equivalent variation</td>
</tr>
<tr>
<td>1. ( ITC_x )</td>
<td>0.0%</td>
<td>-1.3%</td>
</tr>
<tr>
<td>2. Personal income tax</td>
<td>0.2</td>
<td>-0.8</td>
</tr>
<tr>
<td>3. ( ITC_y )</td>
<td>0.7</td>
<td>-1.5</td>
</tr>
<tr>
<td>4. Corporate income tax</td>
<td>0.8</td>
<td>-1.8</td>
</tr>
<tr>
<td>5. ( ITC_{RD} )</td>
<td>45.4</td>
<td>-45.6</td>
</tr>
</tbody>
</table>

Rossi (1993) suggest that 7.09 is a reasonable value for \( \eta \). Columns 4 and 5 show the results when \( \eta \) is increased to 7.0. Although \( \eta \) has a small effect on the absolute size of the responses, it does not affect the ranking.

The previous experiments assume that all government spending is allocated to infrastructure and that infrastructure spending is adjusted to maintain budget balance. However, governments allocate a substantial portion of expenditure to consumption. Columns 2 and 3 in Table 3 show tax incentive effects when households consume 50% of government spending.\(^{20}\) In this case, budget balance is maintained by adjusting all types of government spending proportionally. Columns 4 and 5 show the effects of adjusting the personal income tax rate to maintain budget balance. The ranking is robust with respect to the method used to finance incentives.

Some taxes influence the effects of others. For example, the corporate income tax and \( ITC_{RD} \) interact in the innovative firm's decision to employ skilled labour in research: firms must have tax liabilities to benefit from the tax credit; thus, the smaller is the corporate income tax rate, the smaller is the benefit from the credit. To check the possibility that interactions between taxes and credits could affect the results, each experiment was rerun after reducing (increasing) the initial value of a single credit (rate) by 10 percentage points. Also, each experiment was rerun after reducing (increasing) all initial tax credits (rates) together. These adjustments do not affect the ranking (not shown in tables).

4.4. Comprehensive R&D tax credits

The larger is the amount of inframarginal R&D, as a proportion of total R&D, the lower the incentive effect of R&D tax credits. If all R&D were inframarginal, the credit rate would effectively be zero. In this case, the incentive granted on all R&D investment is wasted because the R&D would be undertaken without the credit. The experiments above implicitly assume that all

\(^{20}\) Of the remaining government spending 30% goes to infrastructure and 20% to administrative and overhead costs.
**TABLE 3**  
Sensitivity to financing

<table>
<thead>
<tr>
<th>R&amp;D incentive</th>
<th>Change in research effort (2)</th>
<th>Equivalent variation (3)</th>
<th>Change in research effort (4)</th>
<th>Equivalent variation (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $ITC_x$</td>
<td>0.0%</td>
<td>-0.8%</td>
<td>0.0%</td>
<td>-0.7%</td>
</tr>
<tr>
<td>2. Personal income tax</td>
<td>0.1</td>
<td>0.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. $ITC_y$</td>
<td>0.4</td>
<td>-0.8</td>
<td>0.5</td>
<td>-0.5</td>
</tr>
<tr>
<td>4. Corporate income tax</td>
<td>0.5</td>
<td>-0.2</td>
<td>0.6</td>
<td>-0.6</td>
</tr>
<tr>
<td>5. $ITC_{RD}$</td>
<td>17.6</td>
<td>-23.3</td>
<td>21.6</td>
<td>-8.6</td>
</tr>
</tbody>
</table>

R&D investment is marginal and, therefore, responsive to taxes. How large an impact does the difference between inframarginal and marginal R&D have on the response to the R&D tax credit? Comprehensive tax credits reward all, including inframarginal, R&D, while incremental credits attempt to isolate and reward only marginal R&D. In this section the effects of comprehensive and incremental tax credits are examined by comparing the effects of subsidizing inframarginal and marginal R&D.

In the long-run all variables, including the level of R&D, grow at the same constant rate. Therefore, we can get some idea of the effect that rewarding inframarginal R&D has on the per dollar effectiveness of the tax credit by assuming that growth in R&D each period is marginal, the rest being inframarginal. If the statutory credit rate is, say, $X\%$, but only $Y\%$ of R&D spending is marginal, then the effective tax credit rate is approximately $X \times Y\%$. Using a variation on a theme, this can be measured using the same procedure used in the United States for determining the R&D credit on ‘incremental’ R&D. In appendix C it is shown that for an economy with real per capita long-run growth of 3.25%, growth in R&D will be about 7.6%, in the long run. In this case, a statutory credit rate of 20% on all R&D has the same effect as a 1.5% (0.076*0.2) credit rate on marginal R&D.

In this model, increasing a comprehensive credit, at a cost of 1% of initial tax revenue, increases research effort by 1.0% and welfare by 0.4%. Recall (table 1) that when the incremental credit was increased, research effort increased 18.5% and welfare increased 17.6%. On this basis, it appears that per dollar of revenue cost, the incremental credit dominates the comprehensive credit.

Nevertheless, the comprehensive R&D credit outperforms the other tax incentives studied here. To see this, compare the last paragraph with the effects of other tax incentives in table 1. The comprehensive credit generates a slightly larger increase in research effort than reducing the corporate income tax rate. However, welfare increases by a smaller amount.
5. Conclusion

Technical knowledge creates spillovers. However, congestion externalities and diminishing returns in knowledge production exist. Privately financed R&D investment could be inefficiently high or low. Many governments grant tax incentives for R&D, so it is important to measure the costs and benefits of such programs. In this paper a Computable General Equilibrium model is used to study five tax incentives. The incentives are ranked by their effect on research effort. Associated welfare effects are reported. Five results stand out. (1) Incremental and comprehensive R&D tax credits produce relatively large increases in research effort and welfare. (2) Lower corporate income tax rates and ITCs for downstream users of innovative inputs rank second and third. (3) Revenue losses from lower personal income tax rates can produce welfare losses. (4) ITCs for upstream producers of innovative goods are ineffective. (5) Incremental R&D credits dominate comprehensive credits.

Diao, Roe, and Yeldan (1999) study a 6% comprehensive R&D credit financed by a lump sum tax, obtaining a long-run increase in welfare of about 36%. Ghosh (2003) studies a $1 billion comprehensive R&D credit financed by a uniform increase in sales taxes, obtaining a long-run increase in welfare of 8.9%. In this paper, an R&D credit that initially costs 1% of revenue and is financed by a decrease in productive government infrastructure, produces a long-run increase in welfare of 17.6%. If government infrastructure in the model is not productive, the welfare increase is 45.6%. There are two major reasons for the differences. First, Diao et al. and Ghosh study open economies: small open economies obtain large benefits from foreign R&D, which increase welfare gains because domestic R&D increases the efficiency with which domestic researchers exploit foreign R&D (Coe and Helpman 1995). Second, I include congestion from duplicated research effort and diminishing marginal returns in knowledge, which decreases welfare gains. Thus, the simulation results in this paper underestimate welfare gains, because foreign trade is excluded from the model, while simulation results in their papers overestimate welfare gains, because their models exclude congestion and diminishing marginal returns. Nevertheless, the results are consistent: R&D tax credits always dominate other incentives: trade policy in their model, income taxes in this model. Given the different modelling approaches and incentives studied, the results complement one another.

Many more issues than are addressed here should be considered in policy discussions. First, the model does not include administration and compliance costs. Tax rate cuts are simpler to implement and comply with than ITCs, so including these costs would increase the welfare gains from income tax cuts. Second, the model does not include uncertainty. R&D markets are plagued by incomplete information and moral hazard (Stiglitz 1993; Hall 1992; Aghion and Howitt 1998; Hall 2002). Credit constrained innovators tend to be less responsive to incentives. But credit constraints probably reduce the stimulative
effect of tax incentives in general; there is no obvious reason why they should affect the ranking. Third, tools other than R&D incentives are available: for example, incubators for start-ups, programs to foster business and academic collaborative research, and programs designed to increase the supply of scientists and engineers (for alternative policies see Lerner 1999; Wallsten 2000; Trajtenberg 2001).

Fourth, R&D tax incentives present severe design and implementation problems. Unless the credit is fully refundable, firms with low income receive lower benefits. It may be hard to monitor program participants, and re-labelling ordinary spending 'R&D' may be easy. A good deal of R&D is inframarginal and would occur without incentives, thus wasting some revenue. It is difficult to design an incremental credit that isolates marginal R&D. If R&D tax credits achieve their goals, they eventually lead to higher sales. In this case, higher current R&D reduces future incremental credits, even for systems using sales in the tax credit base. Attempts to overcome these difficulties invariably increase complexity. As often occurs in public finance, in this case, too, simplicity and economic efficiency are adversaries. Policy makers, not academic economists, must weigh the trade-offs. Good policy formation requires quantitative measures of costs as well as benefits. The comparisons offered here provide a measure of the cost of simplicity.

Appendix A: Endogenous labour supply and government infrastructure

The model used in this paper augments Lin and Russo (2002) with endogenous labour supply and government infrastructure. In this appendix these modifications are briefly described. Since labour supply is endogenous, the household's lifetime utility function is defined as

$$U = \int_0^\infty e^{-(\rho-g_L)t} \frac{c(t)[1-l(t)]^{1-\sigma}}{1-\sigma} -1 dt; 0 < \sigma, 0 \leq \eta,$$

(A1)

where $g_L$ is the exogenous population growth rate, $\rho$ is the rate of time preference, $c(t)$ is per capita private spending on commodities at time $t$, $\sigma$ is

21 Hall and Van Reenan (1999) suggest that design and implementation may be more important than statutory values.
22 Although credits can be carried forward, carry-forwards have less value in present value terms.
23 The Report of the Technical Committee on Business Taxation recommended against Canada's return to an incremental credit (Department of Finance Canada 1997b). According to the report, almost any definition of the base amount discourages R&D because it penalizes successful research firms (that is, their credits are reduced). The effectiveness of incremental incentives can be undermined by tax-planning techniques, so their design is necessarily complex. The incremental credit used in Canada between 1978 and 1983 received severe criticism from research firms, for this reason.
the elasticity of marginal utility, the fraction \( \ell \) of the unit time endowment is supplied as labour, and \( \eta \) determines the wage elasticity of labour supply. (A1) is equation (1) in Lin and Russo (2002) with labour added: It is based on the utility functions used in Lucas (1990), and Jones, Manuelli, and Rossi (1993). The household Euler equation becomes

\[
g_c = \frac{1}{\sigma} \left[ (1 - \tau^P)r - \rho + \eta(\sigma - 1)g_i \frac{l}{1 - l} \right],
\]

where \( g_c \) is the growth rate of consumption, \( \tau^P \) is the tax rate on personal income, and \( g_i \) is the growth rate of labour.

Since government infrastructure is used to balance the government budget, production of final goods is defined as

\[
y = [(1 - \zeta)l]^{\alpha \varepsilon} \int_{0}^{A} x(i)^{1-\alpha} di; 0 < \alpha < 1, 0 \leq \varepsilon < 1,
\]

where \( y \) is the per capita flow of final goods, \( (1 - \zeta) \) is the fraction of skilled labour employed in final goods production, \( \alpha \) is the elasticity of final output with respect to labour, \( x(i) \) is the per capita quantity of the \( i \)th innovative input, and \( A \) is the level of technology. (A3) is equation (4) from Lin and Russo (2002), after including government infrastructure spending and eliminating unskilled labour, which plays no role here. (A3) is constant returns in \( l \) and the \( x(i) \). It is increasing returns in these inputs together with \( A \). \( \tilde{g} \equiv gis/A \) is normalized per capita government infrastructure spending (\( gis \)) and \( \varepsilon \) is the government infrastructure elasticity of final goods production. The normalization \( \tilde{g} \equiv gis/A \) accounts for congestion in government infrastructure in a way similar to that suggested by Barro and Sala-i-Martin (1999). To attain balanced growth \( gis \) must grow at the same rate as \( A \).

Appendix B: Eliminating scale effects and transformation to per capita values

In this appendix it is shown how Jones’s approach is used here to eliminate the scale effects and how the output of the computer simulations, in effective labour units, is transformed into per capita units.

Uninternalized costs and benefits of technical knowledge production affect the aggregate stock of knowledge, but are ignored by individual firms (Jones 1995). It is difficult to quantify the spillovers, since the aggregate knowledge stock is not directly measurable. Lin and Russo (2002) use the following method. The individual innovator’s production of technical knowledge is given by
\[ \dot{A} = \tilde{\delta} \zeta h L A^\lambda; \quad 0 < \lambda < 1, \]  

\text{(B1)}

where \( A \) is the level of technical knowledge, \( \tilde{\delta} \) is a productivity parameter \( \tilde{\delta} = \delta(\zeta h L)^{-\theta} \) with \( \theta > 0 \), \( \zeta \) is the proportion of skilled labour employed in research, \( L \) is the labour force, \( h \) is the proportion of \( L \) endowed with skill, and \( \lambda \) captures the extent of technical knowledge spillovers. If \( \lambda = 0 \), no spillovers occur. Romer (1990) assumed \( \lambda = 1 \) (Constant Returns to Scale in knowledge), but \( \lambda \) this large produces counterfactual scale effects. As well, researchers tend to undertake the most profitable investment opportunities first, so there are diminishing marginal returns in production of technical knowledge, so \( 0 < \lambda < 1 \). \( \tilde{\theta} > 0 \) captures the congestion externality resulting from duplicated research effort. An increase in employment of skilled labour reduces \( \delta \), thus reducing individual firms’ research productivity.

Substitute \( \tilde{\delta} = \delta(\zeta h L)^{-\theta} \) in (B1), and divide by \( A \), to get the aggregate growth rate of technical knowledge, \( g_A = \delta(\zeta h L)^{-\theta} A^{\lambda - 1} \), with \( \theta = 1 - \tilde{\theta} \). \( \theta \) is the elasticity of aggregate technical knowledge with respect to skilled labour. Taking logs of \( g_A \) gives

\[ \log[g_A] = \log[\delta] + \theta(\log[\zeta] + \log[h] + \log[L]) + (\lambda - 1) \log[A], \]  

\text{(B2)}

The tax responsive variables in equation (B2) are \( \zeta \) and \( A \). Therefore, the change in \( \log[g_A] \) resulting from a change in taxes is (approximately)

\[ \% \Delta A \approx \frac{\theta}{1 - \lambda} \% \Delta \zeta. \]  

\text{(B3)}

Equation (B3) uses the fact that the tax cut does not affect the long-run growth rate of technical knowledge in this model (since there are no scale effects), so \( \% \Delta g_A = 0 \). Numerical solution of the model is used to quantify tax-induced changes in \( \zeta \). Given estimates of \( \theta \) and \( \lambda \), equation (B3) generates an estimate of tax-induced change in \( A \). Solution of the model also produces a measure of tax-induced change in \( \tilde{c} \), consumption being measured in efficiency labour units. Since \( \tilde{c} = c / A \), tax-induced change in per capita consumption is calculated from \( \% \Delta c \approx \% \Delta \tilde{c} + \% \Delta A \). The value of a tax-induced change in the level of technical knowledge is then measured as the change in utility resulting from the change in lifetime consumption per capita.

Values of \( \theta \) and \( \lambda \) are needed to implement this procedure. We use the following argument from Jones (1995): the growth rate of technical knowledge is, \( g_A = \delta(\zeta h L)^{\theta} A^{\lambda - 1} \). Empirical evidence rules out scale effects, so the growth rate cannot accelerate in the long run. Therefore, the long-run values of \( g_A \), \( \delta \), and \( \zeta h \) are constant, and
\[
\frac{\dot{g}_A}{g_A} = \theta g_L - (1 - \lambda)g_A = 0.
\]

implying \(\lambda = 1 - (\theta g_L / g_A)\). Given \(g_A\), \(g_L\), and an estimate of \(\theta\), we construct an estimate of \(\lambda\). This leaves \(\theta\) as the single unknown parameter. Kortum (1993) estimates \(\theta\) to be between 0.2 and 0.6. Jones (1995) suggests \(\theta\) is likely to exceed 0.5 because lower values imply ‘large negative externalities.’ Thompson’s (1996) comprehensive study estimates R&D elasticities of research output for 13 SIC industries. Nearly all of Thompson’s many estimates lie in the interval (0.5, 1.0). Jones and Williams’s estimates (1998, 2000) suggest 0.5 is a lower bound. In the simulations \(\theta\) is set equal to 0.85. Given this value and the long-run values for \(g_L\) and \(g_A\) of about 1% and 1.75%, \(\lambda\) equals about 0.51. Values of \(\theta\) of 0.5 and 1.0 produce \(\lambda\)s of 0.71 and 0.43. \(\lambda\)s in this range do not affect the rankings of R&D tax incentives. The ranking is insensitive to \(\lambda\), primarily, because \(\lambda\) (duplication of research effort) has similar negative effects on the stimulative power of each incentive.

Appendix C: Measuring the effective R&D credit rate of a comprehensive credit

The effective credit rate of a comprehensive R&D credit is derived, assuming that inframarginal R&D grows with the economy in the long run. Interestingly, this can be accomplished using the same procedure used by U.S. tax authorities to calculate the incremental R&D credit. In this case, the credit applies to the spending above a Base Amount (BA). BA is the product of a Fixed Base Percentage (FBP) and Average Gross Receipts (AGR) in the four years prior to the credit year. FBP is the ratio of R&D to Gross Receipts (GR) in a prior year:

\[
FPB_{t-i} = \frac{R&D_{t-i}}{GR_{t-i}}, \quad (C1)
\]

Along the economy’s long-run balanced-growth path, R&D and GR must grow at constant and equal rates, so FBP must be constant. This implies

\[
GR_{t-i} = \frac{R&D_{t-i}}{FBP}. \quad (C2)
\]

Thus, AGR and BA can be expressed in terms of lagged R&D

\[
AGR = \frac{1}{4} \sum_{i=1}^{4} GR_{t-i} = \frac{1}{4*FBP} \sum_{i=1}^{4} R&D_{t-i}, \quad (C3)
\]

\[
BA = FBP*AGR = FBP \left( \frac{1}{4*FBP} \sum_{i=1}^{4} R&D_{t-i} \right) = \frac{1}{4} \sum_{i=1}^{4} R&D_{t-i}. \quad (C4)
\]
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Along the economy's balanced growth path, \( R&D_{t-i} = R&D_t \left(1 + g_Y\right)^{-i} \), where \( g_Y \) is the economy's constant long-run growth rate. Using this to replace \( R&D_{t-i} \) in (C4), and simplifying, the increase in R&D at time \( t \) is

\[
\Delta R&D_t = R&D_t \left(1 - \frac{1}{4} \sum_{i=1}^{4} (1 + g_Y)^{-i}\right). \tag{C5}
\]

The expression in parentheses is the ratio of the increase in R&D to total R&D. If the tax credit is restricted to the increase in \( R&D \), therefore, the balanced growth effective credit rate is

\[
ECR = ITC_{RD}^{R&D} \left(1 - \frac{1}{4} \sum_{i=1}^{4} (1 + g_Y)^{-i}\right), \tag{C6}
\]

where \( ITC_{RD}^{R&D} \) is the statutory credit rate. The paper assumes the economy grows 3.25% per year. In this case, R&D grows by 7.6% of the base. If the statutory rate is 20%, ECR is 1.53%.

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