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THE R&D EFFORT AND TAXATION OF CAPITAL INCOME[1)]

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ABSTRACT: The paper shows that non-harmonized tax treatment of capital income from different sources results in a kind of bifurcation effect on the R&D effort of a firm. It is proved that an increase in the tax on income from alternative assets like financial investments leads to postponed completion of research projects with a high anticipated reward while the opposite holds for projects with a low reward. Alternatively, projects with high relative marginal productivity will be slowed down. This bifurcation property holds in the inverted form for the capital gains tax. It follows that a reduction in the rate of interest not only alters the distribution of low and high productivity capital in the aggregate sense but may actually slow down capital investments by delaying disembodied technical progress. The paper also proves the neutrality of the profits tax on the optimal completion time of an R&D project and extends the validity of the Johansson-Samuelson Theorem to R&D spending.

KEY WORDS: R&D, Taxation, Optimal Completion

I Introduction

A comprehensive set of results exists in the literature concerning the tax effects on investment policy of a firm assumed to operate under conditions of neoclassical production technology with tangible inputs. A well-known result in this literature, called the Johansson-Samuelson Theorem, suggests that uniform tax treatment of capital income from different sources saves the tax system from creating allocational distortions as to real investments.[1] Different types of spending by a firm will, however, generate an array of different assets. No results are available so far concerning the tax effects on intangible assets created, for example, through the firm's R&D effort. It is the task of the current paper to address this question. It will be shown that these effects may change the conventional thinking about the tax effects in general and about the relationship between the cost of capital and the capital formation in particular.

The paper formulates a model of a firm which not only has access to the currently existing production technology but which also has access to research technology. The firm will be regarded as having committed itself to a R&D program and its problem is to solve the optimal timing of its R&D budget. It anticipates that completion of the project will lead to a reward, measured by the present value of rents due to increased productivity of the capital assets that the firm currently commands.

The firm encounters conflicting mechanisms in the optimal timing of R&D outlays. The optimal completion time hinges upon the gains from an early completion including the after-tax real interest on the rents created together with cost savings relative to the marginal productivity of the research spending. Given the completion time and due to the concavity of the research technology, there are incentives not only to spread out the spending but also to have an immediate start-up. However, the existence of a positive after-tax real rate of interest favours postponing R&D expenses due to the discounting effect.

The paper finds, not unexpectedly, that the validity of the Johansson-Samuelson Theorem carries over to the optimal R&D spending of a firm. However, since full harmonization of the tax rates is a rather special case, the focus will be on the case where the tax treatment of capital income from different sources is unharmonized. Of special interest are the tax rates which, when differentiated, interact with the firm's discount rate. The tax on interest income is of importance because it depresses the opportunity cost. Second, the capital gains tax is relevant because the R&D spending are assumed to be internally financed from earnings retained by the firm.

The corporation tax will fall on the rents created by the R&D program. It will be proved, however, that this tax is irrelevant for the optimal time span of the R&D spending as will be the tax on profit distributions.

As its major result, the paper finds that the effects of taxes on interest income and on capital gains display a kind of bifurcation property. Depending on the precise magnitude of the rents or reward the R&D program is anticipated to generate, a (permanent) change in the tax rates alters differently the conflicting forces which determine the optimal time span of the project. As an example, consider the effects of a rise in the tax rate on interest income. With a high expected reward, the reduction in gains from early completion dominates leading to postponement of completion. But with a lower expected reward, the incentive for earlier completion on the spending side is raised more. The effects of the tax on capital gains are the reverse. A good guess is that these findings have to be related to the phenomenon of multiple internal rates of return for cash flows with negative terms at the end. This is indeed the case, cf. section III where a simple example is provided.

If anything, there is a very important corollary to the findings above. The capital income tax system which was understood to be neutral will indirectly influence both the accumulation and the quality of the aggregate stock of tangible capital. As is well-known, under interest deductibility and economic depreciation capital taxes do not distort the accumulation of tangible assets, per se. However, the current paper suggests an indirect mechanism which is of major interest. A change in the after-tax rate of interest will alter the quality of the aggregate capital stock in the economy by changing the mixture of high and low productivity capital. For those firms which expect a high reward on the R&D effort or which possess a research technology with a high marginal productivity, an increase in the tax on interest will delay the optimal completion. The effect is quite the opposite for firms which anticipate a lower reward or which possess a less efficient research technology.

It is quite important not to leave unmentioned that these tax effects which work through disembodied technical progress need not distort the equilibrium marginal return to capital. But they surely distort the timing of capital accumulation and the composition of old and new capital in the economy during the adjustment. Taking one more step, a claim can be made that a current increase in the after-tax rate of interest may, after a while, speed up the accumulation of capital. This result which at any rate is in conflict with the traditional thinking is based on the changed incentives for R&D effort. An increase in the rate of interest speeds up those R&D projects which are associated with high economic rewards.

Section II of the paper formulates the model and the properties of its solution are studied in section III. Section IV derives the theorems concerning the tax effects. Some final remarks are presented in the concluding section. The proofs of the results of the paper are rather complicated. However, most of the technical material is presented in three appendixes while the main text emphasizes the interpretation of the results.

II Taxes and the R&D Programs

II.1 Production and Research Technologies. Assume that a firm can invest in capital assets (K_t) to produce an output with the existing technology, denoted by $F(K_t)$. The function F is assumed to be continuously differentiable and of the constant returns to scale type with $F'(K) > 0$. Moreover, assume that the firm can, alternatively, spend its resources on an R&D project, say at a rate $c_t \geq 0$, in order to enhance the efficiency of the existing assets. Then assume that the return on the R&D effort comes in the form of a breakthrough or invention at some later stage, say $t = T > 0$. This invention is anticipated to shift change the production function to $G(K_{t'})$, $t' \geq T$. According to the prevailing terminology, the resulting technical progress is of disembodied type, though it is most appropriate to interpret it as being imbedded in the human capital of the management.

It is assumed that $G(K)$ is of the diminishing returns type to allow the firm to capture the rent on its project. This assumption is, of course, quite necessary for the existence of the incentives for innovating activity. It is also assumed that $G(K)$ is twice continuously differentiable and concave with $G'(K) > 0$, $G''(K) < 0$. Finally, the following assumptions concerning the average and the marginal productivities at time T are made:

(1) $$G(K_T)/F(K_T) > 1, \quad G'(K_T)/F'(K_T) \geq 1.$$

Following the seminal contribution of Lucas (1971) and the subsequent extension by Grossman and Shapiro (1986), assume that completion of the project requires that the accumulated progress in the creation of new know-how has achieved some exogenously given level R. The research technology, i.e. the progress function per unit of time, is given by $h(c_t)$, which is assumed to be continuous and concave in c_t. Thus, completion time is the minimum T satisfying

(2) $$\int_0^T h(c_t)dt \geq R.$$

where $h(0) = 0$, $h'(c_t) > 0$, $h''(c_t) < 0$. While R measures the total required progress, $h'(.)/h(.)$ gives the relative marginal productivity of the research technology. Apparently, different firms may be endowed with research technology with widely diverging levels of productivity.

II.2 Corporate Taxes. Let $0 < \tau < 1$ denote the corporate tax rate and $0 < \phi < 1$ the economic depreciation of K. Assume that the principle of immediate write-off applies to the R&D outlays. Introduce also an extra tax subsidy, proportional to the R&D spending, through a parameter $g \geq 1$. Then the tax liabilities per unit of time over periods $(0,T)$ and (T,∞) are given by $\tau[F(K) - (r+\phi)K - gc]$ and $\tau[G(K) - (r+\phi)K]$, respectively. Hence, it is explicitly assumed that capital investments are financed from a source whose cost, given by r, is fully deductible from the tax base. The R&D program, however, is assumed to be internally financed.[2] These assumptions concerning the firm's finance are not only most natural for the purposes of the current analysis. They are also the most useful if only because they help clarify the mechanisms on which the paper will focus i.e. they eliminate unwanted distortive effects of taxation.

II.3 Personal Taxes and Optimality Conditions. The firm is assumed to look for a spending program that maximizes its present value (V) net of the corporate taxes. If $V_0(K_0)$ is that value with K_0 as the initial capital, the program satisfies

$$(3) \quad V_o(K_o) = \min_{\mu} \max_{K_t, c_t, T} \{\int_o^T \theta[[F(K_t)-(r+\phi)K_t](1-\tau) - (1-\tau g)c_t]e^{-\sigma t}dt + \mu[\int_o^T h(c_t)dt - R] + \int_T^{\infty} \theta[G(K_t) - (r+\phi)K_t](1-\tau)e^{-\sigma t}dt\}.$$

In (3), differentiated taxation of capital income has been introduced with τ_d, τ_r and τ_c denoting the personal tax rates on distributed profits, income from alternative assets like financial investments (with an interest rate r), and capital gains (on accrual basis). Moreover, $\theta = (1-\tau_d)/(1-\tau_c)$ and $\sigma = (1-\tau_r)r/(1-\tau_c)$. Taxes on interest income and capital gains have opposite effects through the discount rate. The capital gains tax becomes relevant because there are retentions along the optimal path not only to finance the capital replacement but also the whole R&D program. Letting the lower bound of the first integral in (3) change by $d\epsilon$, it is easy to see that (3) can be derived from the non-arbitrage condition $(1-\tau_c)dV/d\epsilon = (1-\tau_r)rV(\epsilon) -(1-\tau_d)\pi_\epsilon$, where π stands for the profit distributions after corporation tax. The variable $\mu = -\delta V/\delta R > 0$ in (3) is the shadow price of the constraint. It is time-invariant.

The principle of dynamic programing dictates that maximization of the last integral alone in (3) with the value function

$e^{-\sigma T}\theta(1-\tau)V^*(K_T^+)$ has to be part of the optimal program. Here $V^*(K_T^+)$ refers to max[V], evaluated immediately after T. It is the present value of the pre-tax rents on the R&D program. Note that the value of the rents or the prize $V^*(K_T^+)$ is independent of T. Note also that the corporation tax falls on these rents. The absence of costs of adjusting K frees the firm from a transversality condition with respect to K_T^-. Consequently, if the optimal program dictates that K_T^+ differs from K_T^-, there will be a discrete jump in K_t at $t = T$. Our assumption (1) suggests that the jump will be non-negative.

The Maximum Principle under variable final time (cf. Seierstad and Sydsaeter (1987), Theorem 11) can be used to derive the necessary conditions for optimality as

(4a) $$F'(K_t) = r + \phi = G'(K_{t'}) \qquad t < T,\ t' > T$$

(4b) $$h'(c_t) = \theta(1-\tau g)/\mu e^{\sigma t} \qquad t \leq T$$

(4c) $$h(c_T)/h'(c_T) = \sigma V^*(K_T+)(1-\tau)/(1-\tau g) + c_T.$$

(4d) $$\int_0^T h(c_t)dt - R = 0.$$

The case $g = 1$ will be studied first. Equation (4b) suggests that the optimal R&D effort, provided it is optimal to spread it out over time and start at $t = 0$, is an increasing function of t for $0 \leq t \leq T$. This follows from the fact that the tax-adjusted rate of interest, i.e. the price of waiting is positive. In the absence of the discounting effect, it would clearly be optimal to spread the R&D spending evenly over $[0,T]$. Equation (4c) has been derived under the condition that the technology F is of the constant returns to scale type with $F'(K_T^-) = (r + \phi)K_T^-$. It is the equation (4c) that alone can be used to solve for the terminal R&D effort c_T since the right-hand side is the marginal return on completing the project a moment earlier while the left-hand side is the marginal cost. It should be noted that the corporate profits tax does not show up in the optimality condition (4c) as it enters multiplicatively on both sides and hence cancels.

III Properties of the Solution

The conditions (4b)-(4d), which control the optimal policy, reveal the conflicting mechanisms. As to the optimal T, the gain from a marginal postponing is given by the left-hand side of (4c) which also can be expressed in the form $h(c_T)/h'(c_T) = -(\delta c_T/\delta T)_{R=const.}$ (Differentiate (4d) to see this). The costs at the margin include the foregone gain from earlier completion, $\sigma V^*(.)$ in addition to the required terminal R&D spending, c_T. Capital income taxes affect the optimal completion time through their effects on firms' discount rates. A reduction in the discount rate will, on the spending side, favor early R&D spending and hence earlier completion. On the benefit side, the after-tax gain from having an earlier completion is reduced. The latter is given by the after-tax discount rate times the reward from completion.

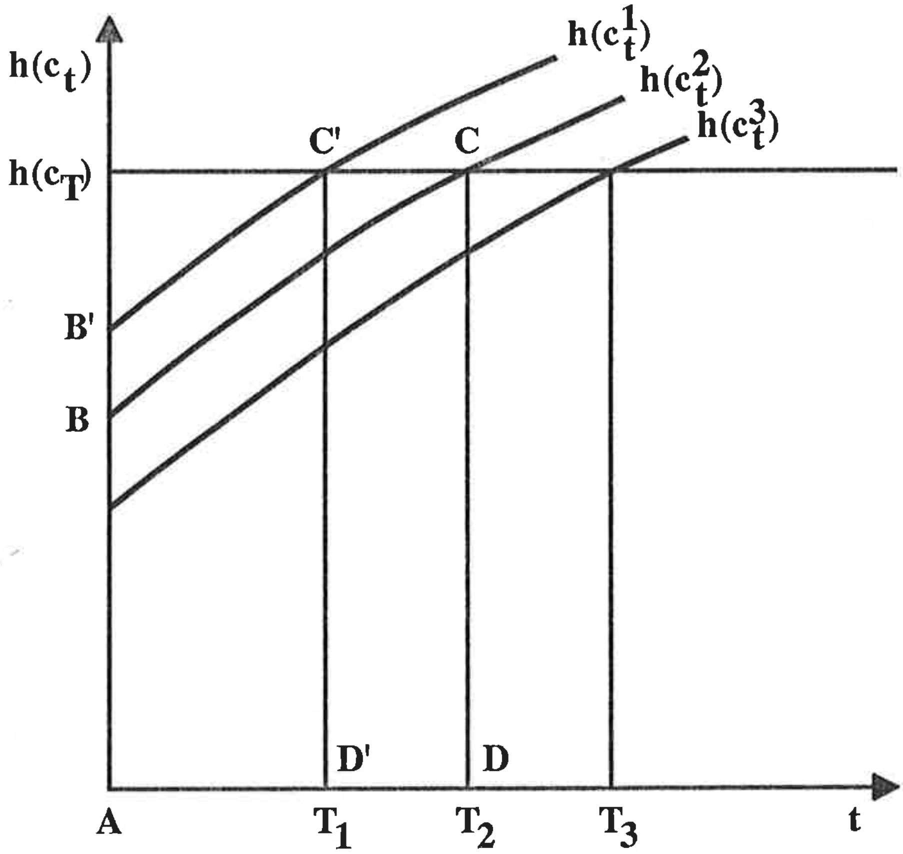
The conditions (4a)-(4d) are all interrelated. But for gaining a better intuition, it is helpful to study them separately. If only for illustrative purposes, take the optimal completion time T as given for a moment to study the conflicting forces behind the allocation of the R&D spending over [0,T]. It turns out that the concavity of the research technology together with the discount effect determines the optimal timing of the R&D spending over [0,T]. From (4b), it is optimal to spread the R&D spending so as to keep $h'(c_t)/\exp\{-\sigma t\}$ = constant for all $t \in [0,T]$. The firm is balancing between counteracting mechanisms of declining marginal productivity and the discount effect. There is a reward for waiting due to the discount effect, which creates an incentive to postpone the R&D spending as much as possible. However, this effect is weakened by the concavity of the research technology, which calls for spreading the R&D effort more evenly over the time span of the project. For any given discount rate, it is optimal to start the program at time 0 and let the marginal productivity of R&D decline over the interval [0,T] by accelerating the R&D spending. An increase in the discount rate, however, will tilt the optimal path such that the firm will reduce the initial spending while letting the acceleration be faster with higher terminal spending.[3]

The multiplicity of finite completion times that satisfy the resource requirement (4d), however, means that any doubt about the uniqueness of the path satisfying the rest of the first-order conditions has to be eliminated. Denote $f(c_T) = h(c_T)/h'(c_T) - c_T$. Then f(.) is everywhere continuous with $f' = - h''h/(h')^2 > 0$ everywhere. This monotonicity property is sufficient to establish the uniqueness of the terminal effort c_T that satisfies the first-order condition (4c). Note that the economic determinants of the optimal terminal effort include the discount rate σ, the prize V*, and the relative marginal productivity.

The uniqueness of the optimal completion time T is most easily proved graphically. A family of the candidate paths is presented in figure 1. The figure is constructed using concave hypothetical paths, though alternatively they could be convex. Since the candidate paths are non-intersecting, it is clear from this figure that there can exist only one path that satisfies the resource constraint (4d). If BC is this path implying that the area ABCD equals R, no other path like B'C' can possibly qualify. To establish this, move the path BC to the left to B'C' to find that AB'C'D' < ABCD. Finally, uniqueness of the completion time T implies that c_o has to be unique, too. This follows from the continuity of the h(.) function.

Only a sub-set of research technologies, those with $h'(c_s)$ strictly positive for all $c_s > 0$, will make it optimal to

Figure 1. A Family of Potential Paths of Progress



undertake the R&D-project in finite time. If the firm has access to such technology, there is only one path satisfying the optimality conditions (4b)-(4d) as established in this section. What restriction must the discount rate of the firm satisfy to make that path the one which, beyond any doubt, provides the maximal value of $V_o(K_o)$? In other words, under what conditions is the second-order condition satisfied? It is usually not possible to find such conditions (cf. Seierstad and Sydsaeter (1987) p. 145). However, we show below that precise analytic results are obtainable, for example, in the case of logarithmic research technology.

<u>Example.</u> Logarithmic Research Technology

The assumption of logarithmic research technology, $h(c_t) = \ln c_t$, is useful due to its property that $c_t > 0$ over $[0,T]$ where T consequently has to be finite. This follows from $\lim_{c\to o+} 1/c_t = \infty$. However, to exclude negative progress, assume $h(c_t) = \ln c_t$, with $c_t > c^m = 1$ for $0 \leq t \leq T$. This amounts to assuming that there is a minimal required effort, c^m, for any progress to be made but such that the incentives for undertaking the project in finite time are preserved. Using the resource constraint (4d), one can solve for $\ln c_o = R/T - \sigma T/2$, $\ln c_t = R/T + \sigma(t-T/2)$, $\ln c_T = R/T + \sigma T/2$. Then along the path which satisfies the first-order conditions it holds that $c_t = \mu\exp\{\sigma t\}$, $c_o = \mu$, and the candidate h(.)-functions appear linear in figure 1.

Appendix A proves that the first-order conditions are also sufficient for optimality of this path provided the discount rate satisfies the requirement $\sigma < 2R/T$.

IV Optimal Behavior under Taxation

It is now our task to determine the tax effects on the optimal R&D spending. Note that there may be indirect effects on the timing of adjustment of the capital stock, too, even though (4a) points to the conclusion that the efficiency condition is not violated. This is so because any change in the time span of an R&D project will influence the timing of capital investment.[4]

It is the tax-adjusted real rate of interest which dictates the required return on a firm's investment policy, including its R&D spending. Hence, the tax rates on interest income and on capital gains are of central interest together with the tax on firm's profits. Since the effects of taxing capital gains are just the opposite to those of taxing interest income, the former need no separate analysis.

The concavity of the research technology is important not only for the optimal pattern of the R&D outlays over time. It also dictates the optimal adjustment of the firm in face of the government's tax policy. Anticipating the formal derivation in Appendix B, we need the condition

(5) $$1 + \alpha\sigma E_1 > 0$$

where $\alpha = [h'(c_T)]^2/h(c_T)$ and where E_1 is given in (7a) below. This amounts to claiming $\alpha < -1/\sigma E_1$ for any given E_1 and $E_1 > -1/\alpha\sigma$ for any given α. In other words, while $h'(c_T)$ cannot be too high, the absolute value of $h''(c_t)$ has to be "high enough". If (5) holds, the concavity of the research technology will be sufficient for the proof of the following proposition:

Theorem 1. (Bifurcation Theorem) A ceteris paribus increase in the tax rate on interest income will unambiguously reduce the terminal R&D spending. Moreover, provided (5) holds, it is optimal to postpone the completion of the project if the reward from completion is "high" while it is optimal to complete the project earlier if the reward is "low". In the first case, the initial R&D spending is reduced while it is increased in the latter case. The critical value of the reward is given by

(6) $$V_c^* = (E_2/E_1)h(c_T)/h'(c_T) - \sigma(\delta V^*/\delta\sigma)$$

with

(7a) $$E_1 = \int_0^T [\exp\{2\sigma(T-t)\}/h''(c_t)]dt < 0$$

(7b) $$E_2 = \int_0^T [\exp\{2\sigma(T-t)\}/h''(c_t)](T-t)dt < 0. \quad []$$

The details of the proof can be found in Appendix B. Intuitively, the tax effects hinge upon the following conflicting mechanisms. An increase in the tax rate τ_r reduces the gains from early completion or the sacrifice from postponement of the project. On the expenditure side, a lower after-tax rate of interest favors early spending because the reward for waiting has decreased. Both the optimal duration and the time pattern of the R&D effort will change. What the Bifurcation Theorem states is that there exists a critical value of the reward or prize to the research effort at which the conflicting effects on optimal duration offset each other. For a higher prize, the reduction in the sacrifice from postponement dominates with the consequence that it is optimal to spread out the project over a longer time horizon. For a lower prize, the impact on terminal effort dominates leading to earlier completion. The outcomes are depicted in figures 2a and 2b. Note that in the former, there will be a tilting (crossing) effect, if the reduction in the optimal completion time is not very large.

In Appendix B, the proof of Theorem 1 about the existence of a critical value of reward to research programs that causes

Figure 2a. Optimal Path when V* < V_c *

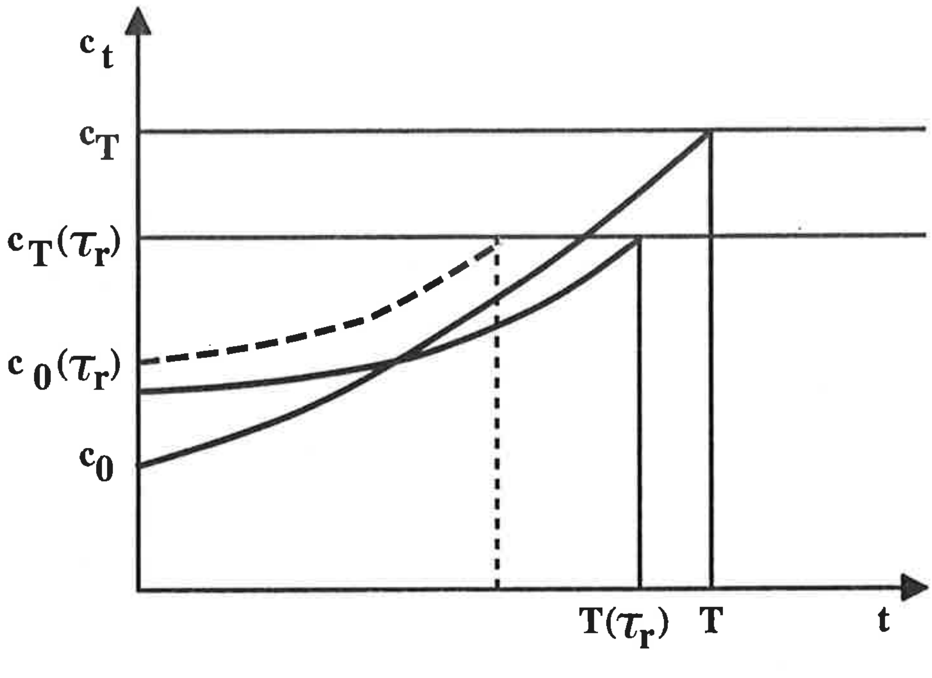
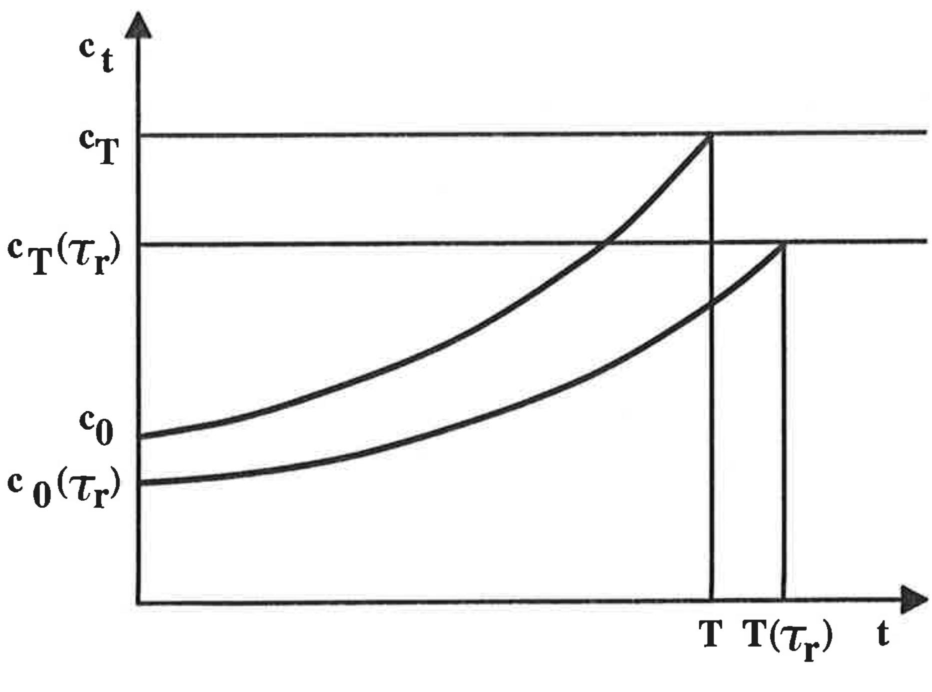


Figure 2b. Optimal Path when V* > V_c *



the bifurcation property for the tax effects was conditional on the concavity of the research technology. Appendix C proves that logarithmic research technology is an example where such a bifurcation - unconditionally - takes place to the direction as suggested by the Bifurcation Theorem.

There is yet another way to state the result above.

> Corollary 1. A reduction in the opportunity cost due to a tax increase will lead to postponement of the completion of R&D projects with high terminal relative marginal productivity.[]

The proof is given in Appendix B in the form of (B.7) and (B.8). Intuitively, if the marginal productivity is high at the end, it is more costly to shift the R&D outlays to earlier periods in which case the reduction in the gains from early completion will dominate. If the marginal cost of early completion, as given by $-dc_T/dT$ on the left-hand side of (B.8) is relatively low, an increase in the tax rate does not alter incentives sufficiently in favour of early spending to counteract the opposite effect that calls for postponement.

As stated in the introduction, our result is related to the case of multiple internal rates of return for cash flows with negative terms at the end. As an illustrative example, consider an asset that generates $1 after two periods. Then suppose that by investing \$2/9 at time 0, one can have this \$1 one period earlier. The present value of this perturbation is $V = -2/9 + p - p^2$ where $p = 1/(1+r)$. The roots of $V = 0$ are $p = (1/3,2/3)$. It holds that $V > 0$ if $p \in (1/3,2/3)$ and $V < 0$ if $p < 1/3$ or $p > 2/3$. If the discount factor is decreased from $p = 1/3$ (r is raised), the profitable project (earlier completion) is made unprofitable. The same happens if the discount factor is increased from $p = 2/3$ (r is decreased).

The above example illustrates the relative importance of the conflicting forces at different levels of internal rates of return, given the reward \$1. This is precisely the problem faced by the firm with an R&D project with variable completion time. A change in the rate of interest may render a profitable change in timing unprofitable and vice versa depending on the magnitude of the reward and the level of the rate of interest. Our model, however, is richer than the above simple example in that the magnitude of the reward itself depends on the level of the rate of interest and the technology and that the amount of investment in R&D is optimized over the research period.

Not surprisingly, a similar type of result has been obtained in the theory of optimal extraction of natural resources with negative cash flows at the end (cf. Asheim (1978). A reference can also be made to Asheim (1980), who shows that the optimal steady state of a growth model with detrimental environmental effects depends on the level of the rate of interest. Moreover, we would like to draw attention to the numerical simulation model by Nielssen and Nystad (1986), who analyze the effects of distortive taxes on optimum exploration and extraction of a petroleum basin.

The Bifurcation Theorem carries an important message for the relationship between the rate of interest and capital accumulation in the economy. This theorem proves that the mere fact that the condition (4a) is satisfied is not sufficient for tax neutrality with regard to capital accumulation. Figure 3a depicts the differentiated timing of a shift to more productive capital in firms with different expected rents (or with different research technology). If the firms with expected rents falling short of the borderline rent V_c* dominate, an increase in the tax on interest income speeds up disembodied technological progress. This improves the average quality of the capital stock in the economy. The opposite is the case if firms of high-rent R&D projects dominate. Note that these tax effects are limited to the impact on timing with no permanent effect on the "long-run" stock of aggregate capital.

A reduction in the pre-tax rate of interest, however, which raises the stock of capital from K_o to K_1 (Figure 3b) before completion of the R&D program and to K_2 after the completion may slow down the investment in productive capital. This

Figure 3a. Increased Tax on Interest and Capital Investment

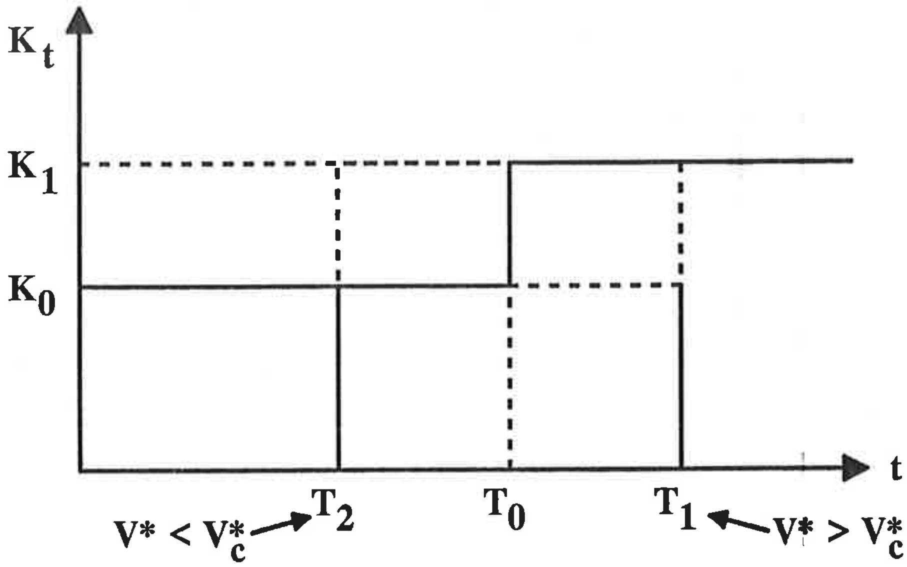
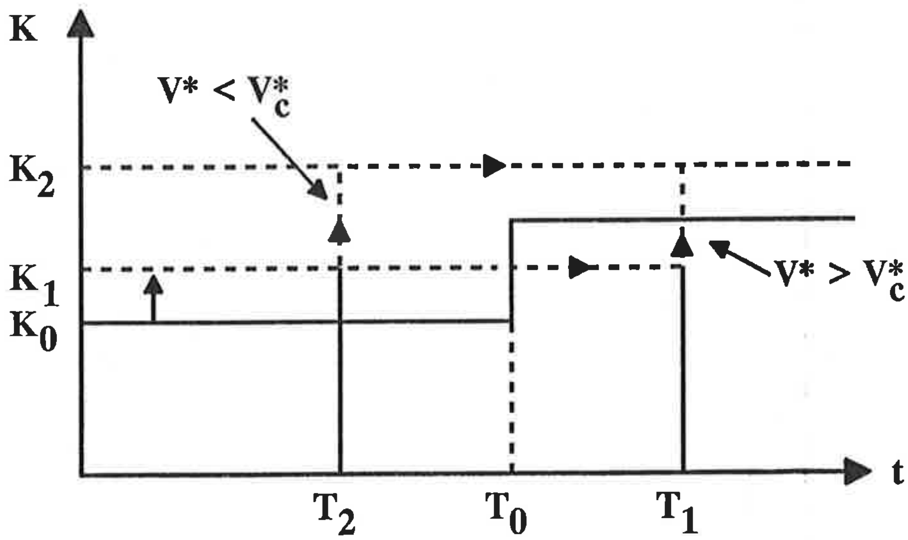


Figure 3b. Adjustment of Capital Investments to Reduced Interest Rate



outcome obtains if those firms dominate which respond to a change in the rate of interest by delaying programs leading to disembodied technical progress. We have

Corollary 2. A reduction in the rate of interest will have an ambiguous effect on the speed of aggregate capital accumulation. Since disembodied technical progress will slow down in firms with high profit margins on new technologies, accumulation of more productive capital may actually be postponed. []

It should be pointed out that this result may provide some light to the often stated difficulty of establishing a systematically negative relationship between the rate of interest and aggregate investment spending. This result suggests that one cannot consider the relationship between the rate of interest and aggregate investment as distinct from the technical progress which simultaneously takes place. Moreover, the larger the profit margins are for innovating firms, the more likely it appears that the R&D programs are delayed. Finally, note that the optimum amount of capital to be invested in new technology seems to be unrelated to the size of the rents.

Let us move on to the corporation tax to prove the following theorem.

<u>Theorem 2.</u> Under immediate write-off of the costs of an R&D project, the corporation tax is neutral with respect to the time pattern of the R&D spending. Its effects are limited to revaluation of the effort constraint. []

This result is as expected because the corporation tax functions like a cash-flow tax. The proof is, however, required and it goes as follows. From (4c), the terminal effort, c_T, is fully independent of the corporation tax. Our uniqueness result discussed earlier says that there can then be at most one path $\{c_t\}$ which satisfies both the resource constraint (4d) and the required terminal effort. If the corporation tax consequently does not interfere with the terminal effort, it cannot induce any changes in the path, either. A change in the corporate tax rate is fully reflected in the shadow price μ. Differentiating (4b) and using $h'(c_t) = h'(c_T)\exp\{\sigma(T-t)\}$, one obtains

(8) $$\delta\mu/\delta\tau = -\theta/h'(c_T)\exp\{\sigma T\} < 0.$$

Intuitively, this valuation effect arises because the government is a fair partner in the sense of increasing the initial R&D subsidy through the higher tax rate. Hence, the negative effect on the value function from an increase in the exogenous resource requirement R would be less the higher the tax rate τ is. A higher tax rate will therefore reduce the price of the constraint.

Neutrality of the corporation tax, as proved above, is easy to explain. Immediate write-offs do not create an incentive for altering the time pattern of the R&D effort because the present value $V^*(K_T^+)$, which is the payoff, will be taxed at the very same rate. This of course, presumes that expectations of changes in the tax rate in the future are ruled out.[5] We also get the following corollary:

Corollary 3. A proportional tax subsidy is not a feasible approach for elimination of the distortions caused by the personal taxes on capital income. []

A proportional subsidy with $g > 1$ in (3) would make the corporation tax distortionary. This follows from Theorem 2. In principle, an attempt could be made to eliminate the distortions caused by the taxes on personal capital income by another distortionary tax. From the first-order conditions given by (4c) one knows, however, that in order to eliminate the distortions in the completion time T by the choice of g, the prerequisite for the tax authority is knowledge of the rewards V^* faced by the firms. It goes without saying that no tax policy can be based on this type of premise.

So far we have said nothing about the tax on corporate dividends. Not quite unexpectedly, is is easy to see from (4b) that the dividend tax operates in this model very much like the corporation tax. It only influences the valuation of the effort constraint with no impact whatsoever on the time path of R&D or on the completion time. This is but one more example of the well-known merits of taxing dividends.

The results reported in this section can be combined to justify the following claim:

Theorem 3. Under capital income taxation at uniform rates, the validity of the Johansson-Samuelson Theorem extends to firms' R&D spending, too. []

It should be noted that in the current model the uniformity requirement does not go beyond the equality between the tax rates on capital gains and financial investments. This is so because from the point of view of capital investments, the corporation tax falls on pure economic profits while from the point of view of the R&D spending it follows the principle of the cash flow tax. Moreover, the role of the dividend tax is limited to valuation effects. Hence, investment neutrality is obtained in the current model even if full harmonization is not achieved.

Finally, it would be easy to show that a personal consumption tax would provide another example of tax neutrality with respect to the R&D spending.

IV Final Remarks

Subsidizing the R&D efforts of firms has been an important policy issue in many countries over the past decades. Indeed, the R&D subsidies have been perhaps one of the most important tools in the industrial policy of many Western governments. In practise, subsidies have taken a variety of forms.[6] The current analysis has suggested important deviations from the efficiency benchmark as to timing and completion of the R&D projects under conditions of non-harmonized taxation of capital income.[7] Given that capital gains are normally taxed much less heavily than are the other forms of capital income like interest, capital taxes, taken altogether, tend to distort firms' R&D efforts to the direction discussed in the current paper.

However, from Corollary 3 it is clear that elimination of the tax distortions discovered in the current work cannot be eliminated by the proportional tax subsidy introduced in section II. This approach would make the corporation tax distortionary without eliminating the intertemporal distortions caused by the personal capital taxes. A proportional subsidy would not make the time spans of the R&D projects fully efficient.[8] Thus, the motivation for this particular type of government intervention has to be sought from other distortions than those caused by the taxes on capital income.

Appendix A. Concavity of the Value Function in the Case of Logarithmic Research Technology

Noting that $c_o = c_o(T)$, the unmaximized value function can be derived from (3) as

$$V(T) = -c_o(T)T + V^*\exp\{-\sigma T\} \quad \text{(A.1)}$$

with derivatives

$$V_T = -c_o - c_o'T - \sigma V^*\exp\{-\sigma T\} \quad \text{(A.2)}$$

$$V_{TT} = -c_o''T - 2c_o' + \sigma^2 V^*\exp\{-\sigma T\}. \quad \text{(A.3)}$$

Along the path satisfying the first-order conditions, $V_T = 0$. Then $V_{TT} < 0$ is equivalent to

$$c_o'' > (c_o/T)[2R/T^2 + \sigma R/T + \sigma^2 T/2] = C \quad \text{(A.4)}$$

where use has been made of $\ln c_o = R/T - \sigma T/2$. The latter also can be used to derive

$$c_o'' = C + (c_o/T)[R^2/T^3 - \sigma^2 T/4]. \quad \text{(A.5)}$$

Then (A.4) is satisfied if

$$\sigma < 2R/T. \quad \text{(A.6)}$$

Appendix B. The Effects of an Increase in the Tax Rate on Interest Income

From (4c), one obtains

$$\text{(B.1)}\quad \delta c_T/\delta\tau_r = -\{V^*\delta\sigma/\delta\tau_r + \sigma\delta V^*/\delta\tau_r\}[h'(c_T)]^2/h''(c_T)h(c_T) < 0.$$

The change in gains from early completion $d(\sigma V^*)/d\tau_r$ consists hence of two conflicting effects. An increase in the tax rate τ_r raises the value of the prize, V^*, by reducing the discount rate σ. These effects enter {.} in (B.1) but with opposite signs. It is, however, the first term which dominates. Then, concavity of the h(.) function guarantees that (B.1) is negative.

Differentiating (2) gives

$$\text{(B.2)}\quad \delta T/\delta\tau_r = -[1/h(c_T)]\int_o^T h'(c_t)(\delta c_t/\delta\tau_r)dt$$

$$= -[h'(c_T)/h(c_T)]\int_o^T \exp\{\sigma(T-t)(\delta c_t/\delta\tau_r)dt$$

because from (4b), $h'(c_t) = h'(c_T)\exp\{\sigma(T-t)\}$. Moreover, from this same condition,

$$\text{(B.3)}\quad \delta c_t/\delta\tau_r = \{h''(c_T)\exp[\sigma(T-t)](\delta c_T/\delta\tau_r) + h'(c_T)\exp\{\sigma(T-t)\}[\sigma\delta T/\delta\tau_r + (T-t)\delta\sigma/\delta\tau_r]\}/h''(c_t).$$

By substituting (B.3) into (B.2) and solving

(B.4) $(\delta T/\delta \tau_r)[1 + \alpha\sigma B_1] = -\beta(\delta c_T/\delta \tau_r)E_1 - \alpha(\delta\sigma/\delta \tau_r)E_2$

where E_1 and E_2 are given in (7a) and (7b)

(7a) $$E_1 = \int_0^T [\exp\{2\sigma(t-T)\}/h''(c_t)]dt < 0$$

(7b) $$E_2 = \int_0^T [\exp\{2\sigma(T-t)\}/h''(c_t)](T-t)dt < 0$$

and where

(B.5) $\alpha = [h'(c_T)]^2/h(c_T) > 0$

(B.6) $\beta = h'(c_T)h''(c_T)/h(c_T) < 0.$

The direction of the tax effect on the optimal completion now hinges upon the sign of the term $1 + \alpha\sigma E_1$. An assumption will be made that the concavity of the research technology is strong enough to keep the parameter α small enough (or alternatively, the absolute value of E_1 small enough so that $1 + \alpha\sigma E_1 > 0$. Then the condition $\delta T/\delta \tau_r > 0$ from (B.4) is equivalent to $\delta c_T/\delta \tau_r < -(\alpha/\beta)(\delta\sigma/\delta \tau_r)(E_2/E_1)$. Substituting into (B.1) gives $V^* > V_c^*$, where V_c^* is given in (6).

Alternatively, the condition $\delta T/\delta \tau_r > 0$ can be written as

(B.7) $h'(c_T)/h(c_T) > (E_2/E_1)[V^* + \sigma(\delta V^*/\delta\sigma)],$

or

(B.8) $\quad (-dc_T/dT) < [V^* + \sigma\delta V^*/\delta\sigma]/(E_2/E_1)$.

The latter condition where the left-hand side is the marginal cost of completing the project a period earlier follows from $d_{cT}/dT = - h(c_T)/h'(c_T)$.

Appendix C. Proof of the Bifurcation Theorem Under Logarithmic Research Technology

The central result (5) was derived above under the assumption that the concavity of the research technology permits the assumption $1 + \alpha\sigma E_1 > 0$. A further justification for this assumption will now be provided. We use logarithmic research technology to establish the existence of the suggested bifurcation property. We prove that a result analogous to (5) unconditionally is valid under logarithmic research technology. With $h(c_t) = \ln c_t$, (4c) reads as $c_T[\ln c_T - 1] - \sigma V^* = 0$, or $\phi(T,\sigma,R,V^*) = 0$ where

$$\text{(C.1)} \quad \phi(T,\sigma,R,V^*) = [R/T + \sigma T/2 - 1]\exp\{R/T + \sigma T/2\} - \sigma V^*$$

with $\phi_T = (-1/T)c_T(\ln c_o)(\ln c_T)$, $\phi_\sigma = (T/2)c_T(\ln c_T) - V^*$. Totally differentiating $\phi(.)$ gives $\delta T/\delta\sigma = - \phi_\sigma/\phi_T > 0$ if $V^* < (T/2)c_T(\ln c_T) = V_{cc}^*$. Recalling that $\delta\sigma/\delta\tau_r < 0$ completes the proof.

Footnotes:

1. This result, which presumes that the principle of economic depreciation holds, has been called the Johansson-Samuelson Theorem since Sinn (1987).

2. Outside the model, this assumption can be motivated by the argument that because of moral hazard, no debt is available for an R&D program.

3. This tilting effect can be proved as follows. From (4b), $h'(c_T)\mu^*\exp(\sigma T) - 1 = 0$ where $\mu^* = \mu/\theta(1-\tau)$. Differentiating gives $\delta\mu^*/\delta\sigma = -[T + (\delta c_T/\delta\sigma)h''(c_T)/h'(c_T)]\mu^*$. From (4b), $\delta c_t/\delta\sigma = -[\delta\mu^*/\delta\sigma + \mu^* t]h'(c_t)/h''(c_t)\mu^*$ or, after substitution,

(F.1) $\delta c_t/\delta\sigma = [T - t + (\delta c_T/\delta\sigma)h''(c_T)/h'(c_T)]h'(c_t)/h''(c_t)$.

Due to concavity of h(.), $\delta c_t/\delta\sigma < 0$ when $t = 0$ (given that $T > -(\delta c_T/\delta\sigma)h''(c_T)/h'(c_T)$ which will ne assumed here). On the other hand, when $t = T$, $\delta c_t/\delta\sigma > 0$ always because the condition (B.1) in Appendix B implies $\delta c_T/\delta\sigma > 0$. (F.1) reveals explicitely that the tilting effect is influenced by the concavity or curvature of the h(.) function, manifested in the ratio of the "elasticities" of the marginal productivity along the path and at the terminal point. The reader recognizes the analogy of this measure and the well-known measure of risk aversion, called "absolute" risk aversion. But remember that the analysis in this footnote has been partial and carried out by keeping T as fixed. To obtain the final answer to the question in which way the path $\{c_t\}$ adjusts when the tax policy is changed, one has to incorporate the endogenous adjustment of T, too. This is done in the main text and presented in figures 2a-2b.

4. In presence of costs of adjusting capital, the tax effects would be time-dependent and hence more dramatic. Since discrete jumps in K_t were ruled out at t = T, it would be optimal for the firm to start the accumulation process prior to t = T.

5. We realize that one should stop to think the meaning of this result more carefully. The mere existence of positive rents suggests that there is some fixed factor in the model. We suggest that it is the human capital or entrepreneurship corresponding to the total required effort, given by the fixed R. If this factor would be supplied elastically, we would predict that the corporation tax would cease to be neutral both with respect to completion time of the R&D program and hence on the timing of capital investments. We plan to look into this issue more carefully in a separate paper.

6. Fölster (1989) has studied the whole menu of these subsidies.

7. For an analysis of an optimal R&D subsidy under differing conditions in the research markets, see Romano (1989).

8. An interest subsidy could be used to manipulate the optimal duration of the projects so as to counteract the undesired tax distortions. But the trouble is that the subsidy should exclude capital investments. This raises awkward administrative problems because the firms would then have incentives to report their capital expenditures increasingly as part of their R&D programs.

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