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ENDOGENOUS TIMING AND THE TAXATION OF DISCRETE INVESTMENT CHOICES

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Abstract

This article discusses the effects of taxation on the discrete choice of alternative projects. In particular, it is shown that if taxation affects the optimal timing of irreversible investment, then the discrete choice is distorted as well. This result has both methodological and political implications.

JEL Classification: H25, H32.

Keywords: effective average tax rate, timing and real options.

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To analyse the impact of taxation on discrete choices, Devereux and Griffith (1998, 1999) propose a forward-looking measure of the effective average tax rate (EATR). However, they implicitly assume that investment timing is exogenous. As argued by Dixit and Pindyck (1994, p.3), instead, 'Most investment decisions share three important characteristics, investment irreversibility, uncertainty and the ability to choose the optimal timing of investment'. Managers are aware that investment is an opportunity and not an obligation. Thus they behave as if they owned option-rights. Moreover, they know that, under irreversibility, their exercise reduces flexibility.

Using a real-option approach, this article discusses the impact of taxation on discrete choices under endogenous timing. We first propose a measure of the EATR embodying the three main features stressed by Dixit and Pindyck (1994). Then, we discuss policy implications. In particular, we show how endogenous timing affects the ranking between alternative projects. To do so, we compare two projects, which ensure the same pre-tax return. However, they differ for the tax treatment. One tax system is characterised by a narrower tax base and a higher statutory tax rate than the other. By assumption, they yield the same post-tax return under exogenous timing as well. Following Devereux and Griffith (1998, 1999), therefore, firms would be indifferent between the two alternatives. Under endogenous timing, instead, firms choose the project with the higher statutory tax rate if volatility is low enough and vice versa.

This result allows us to compare two tax proposals presented in the 90s: the Allowance for Corporate Equity (ACE) and the Comprehensive Business Income Tax (CBIT). As we know the former has a narrower tax base and a higher statutory tax rate than the latter. According to common wisdom, in a small economy, the CBIT is preferable. Due to the lower tax rate, in fact, multinationals, which are usually the most profitable companies, would pay a lighter tax burden. In this paper we show that, under endogenous timing, the converse may be true, i.e. the ACE system may be preferred. Although companies investing in an ACE system pay a heavier tax burden, they start to earn profits earlier. If volatility is low enough, the latter effect dominates the former one. This tradeoff should be taken into account in the EU debate on tax co-ordination.

The paper is structured as follows. Section 2 gives the intuition behind the tax effects on the relationship between intertemporal and discrete choices. Section 3 introduces a continuous-time model and computes the effects of average taxation on the firm's choices. Section 4 proposes a measure of the effective average tax rate under endogenous timing. Section 5 discusses policy implications and, finally, section 6 summarises the results.

2 The relation between intertemporal and discrete choices

This section discusses the effects of taxation on the interaction between intertemporal and discrete choices. We first study investment under exogenous timing. Then we introduce optimal timing and show how the firm's decisions may change.

2.1 Investment timing

Let us define $V_i^T(Y)$ as the post-tax present value of project i, where Y represents current income. To start the project, the firm must pay a sunk cost F. When timing is exogenous, the investment decision arises from the mere comparison between $V_i^T(Y)$ and F, i.e.

$$\max \left\{ E\left[V_i^T(Y) - F \right], 0 \right\}, \tag{1}$$

where $E[.]$ denotes the expectation operator. According to rule (1), if $E\left[V_i^T(Y) - F\right] > 0$, then investment is undertaken. Otherwise, the firm loses the opportunity to invest.

Firms can usually decide when to undertake investment, thereby enjoying a certain degree of flexibility. The value of flexibility can be computed using option pricing techniques. As shown by McDonald and Siegel (1986), in fact, the opportunity to postpone investment is analogous to a call option. Thus, rule (1) is correct only if the value of the option is nil. When, instead, the firm has the possibility of postponing investment, its decision entails choosing an optimal stopping time, i.e.

$$\max_t E\left\{ \left[V_i^T(Y) - F \right] e^{-rt} \right\}, \tag{2}$$

where r is the rik-free interest rate. The solution of problem (2), defined as t_i^*, is the optimal time of investment. If t_i^* differs from that obtained under laissez-faire, say $\widetilde{t}$, taxation distorts investment timing.

2.2 The discrete choice

Suppose now that there exist N mutually alternative projects. By assumption, they yield the same expected pre-tax present value, $V(Y)$, and are profitable, i.e. $V(Y) - F > 0$. Since they differ for the tax treatment, the firm will choose the project with the highest post-tax project. Without the option to delay, the discrete choice is

$$\sup_i \left\langle \max \left\{ E\left[V_i^T(Y) - F \right], 0 \right\} \right\rangle, \text{ with } i = 1, ..., N. \tag{3}$$

When timing is endogenous, instead, the ranking between alternative projects may be affected. Using (2), the firm's discrete choice is

$$\sup_i \left\langle \max_t E\left\{ \left[V_i^T(Y) - F \right] e^{-rt} \right\} \right\rangle, \text{ with } i = 1, ..., N. \tag{4}$$

A comparison between the rules (3) and (4) yields the following

Proposition 1 *Rule (4) ensures the same ranking as rule (3) only if*

1. *delaying the decision is impossible or $t = 0$ is the optimal timing for any project;*
2. *taxation is neutral.*

The former condition is trivial. When the value of flexibility is either zero (i.e. delaying is impossible) or low enough (i.e. $t = 0$ is the optimal timing), the ranking of alternative projects is unaffected by timing. Therefore, rule (4) collapses to rule (3).

The latter condition deserves some comments. Let us start with Brown's (1948) neutrality condition which implicitly assumes exogenous timing. Given the tax rate τ_i, neutrality is ensured if the post-tax net present value is $(1 - \tau_i)$ times the pre-tax net present value, i.e.

$$E\left[V_i^T(Y) - F \right] = (1 - \tau_i) E\left[V(Y) - F \right]. \tag{5}$$

As argued by Johansson (1969), condition (5) implies that an 'identical ranking of alternative investments is obtained in a pre-tax and post-tax profitability analysis' [p. 104]. Under neutrality, therefore, rule (3) can be rewritten as

$$\sup_i \left\langle \max \left\{ E\left[(1 - \tau_i) E\left[V(Y) - F \right] \right], 0 \right\} \right\rangle, \text{ with } i = 1, ..., N. \tag{6}$$

When timing is endogenous, the opportunity cost of flexibility must be considered. Thus, the neutrality condition must be changed as follows

$$\max_t E\left\{ \left[V_i^T(Y) - F \right] e^{-rt} \right\} = (1 - \tau_i) \max_t E\left\{ \left[V(Y) - F \right] e^{-rt} \right\}. \tag{7}$$

If condition (7) holds, it can be shown that optimal timing is unaffected by taxation (see Panteghini, 2001 and 2002). Namely we have $t_i^* = \widetilde{t}$. The neutrality result can be explained as follows. On the one hand, an increase in the tax rate reduces the present value of future discounted profits and induces the firm to delay investment. On the other hand, the increase in the tax rate causes a decrease in the option value, namely in the opportunity cost of investing earlier. This encourages investment. When these effects neutralise each other, taxation does not affect the intertemporal investment decision.

Using the neutral solution $\widetilde{t}$, and substituting (7) into rule (4) yields:

$$\sup_i \left\langle (1-\tau_i) E\left\{ \left[V(Y) - F \right] e^{-r\widetilde{t}} \right\} \right\rangle, \text{with } i = 1, ..., N. \tag{8}$$

As can be seen, rule (8) is just a rescaling of rule (6). Therefore, they yield the same project ranking.

When none of the two conditions of Proposition 1 holds, investment timing and discrete choices are related. In the next sections we will focus on this case.

3 A continuous-time model

Let us introduce a continuous-time model describing the relationship between an intertemporal decision and the discrete choice by a representative firm. The following hypotheses hold[1]:

1. risk is fully diversifiable;
2. current income follows a geometric Brownian motion

$$dY(t) = \alpha Y(t) dt + \sigma Y(t) dz,$$

   where α and σ are the growth rate and variance parameter, respectively;

3. there exists capital risk[2]. This is modelled as sudden death, i.e. the lifetime of investment follows a Poisson process. At any time t there is a probability λdt that the existing project dies during the short internal dt.

[1] The reader may find further details of the model in Dixit and Pindyck (1994, Chapters 5 and 6).

[2] As argued by Bulow and Summers (1984), capital risk is the most important source of risk involved in holding an asset.

Let us next introduce a symmetric tax system[3]. Moreover, the tax base is equal to the firm's current income, net of an imputation rate ρ_i. This rate may account for both fiscal capital depreciation allowances and the cost of finance[4]. For simplicity, hereafter, we will omit the time variable t. Thus, current tax payments of project i are

$$T_i = \tau_i \left(Y - \rho_i F \right). \tag{9}$$

Given (9), the post-tax income is therefore

$$Y_i^T = (1 - \tau_i)Y + \rho_i \tau_i F. \tag{10}$$

Let us then write the firm's post-tax value as a Bellman function

$$V_i^T(Y) = Y_i^T dt + (1 - \lambda dt)e^{-rdt} E\left[V_i^T(Y + dY)\right]. \tag{11}$$

As shown in the Appendix, the solution of (11) is[5]

$$V_i^T(Y) = \frac{(1-\tau_i)Y}{\delta + \lambda} + \frac{\rho_i \tau_i}{r + \lambda} F, \tag{12}$$

where δ is the dividend rate. This must be positive in order for the net value of the firm to be bounded[6].

As shown by Dixit and Pindyck (1994), the option function has the following form

$$O_i^T(Y) = H_i Y^{\beta_1} \tag{13}$$

where $\beta_1 > 1$ is the positive root of the characteristic equation[7]

$$\frac{\sigma^2}{2}\beta(\beta - 1) + (r - \delta)\beta - (r + \lambda) = 0,$$

and H_i is an unknown parameter. Using the Value Matching and Smooth Pasting Conditions one can find the optimal timing solution, which can be expressed as the post-tax trigger point above which investment is profitable

$$Y_i^* \equiv \left[\frac{1 - \frac{\rho_i}{r+\lambda}\tau_i}{1 - \tau_i} \right] \widetilde{Y}, \tag{14}$$

[3]For a discussion on the effects of tax asymmetries see Panteghini (2001).

[4]For further details on the tax base, see Boadway and Bruce (1984).

[5]In the absence of taxation, (12) reduces to $V(Y) = \frac{Y}{\delta+\lambda}$.

[6]Under risk-neutrality, the equality $r - \delta = \alpha$ holds. Following McDonald and Siegel (1985, 1986) we could also assume that the firm is risk-neutral, but its owners may be risk-averse. However, the quality of results would not change.

[7]Note that all the alternative projects share the same deep parameters r, α and σ. Thus they have the same root, i.e. $\beta_1 = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{r-\delta}{\sigma^2}\right)^2 + \frac{2(r+\lambda)}{\sigma^2}}$.

where $\widetilde{Y} \equiv \frac{\beta_1}{\beta_1 - 1} \cdot (\delta + \lambda) F$ is the laissez-faire trigger point. Substituting Y_i^* into the Smooth Pasting Condition, one can also find

$$H_i = \frac{1 - \tau_i}{\beta_1(\delta + \lambda)} {Y_i^*}^{1-\beta_1} > 0. \tag{15}$$

Under the traditional approach (based on the NPV rule), the positive difference between the critical present value of the project, i.e. $\frac{Y_i^*}{\delta+\lambda}$, and the cost F would represent pure profits. In a real-option setting, instead, the wedge $\left(\frac{Y_i^*}{\delta+\lambda} - F\right)$ measures the additional amount of income required to cover the opportunity cost of flexibility. Only when $Y > Y_i^*$, therefore, investment is really profitable.

It is worth noting that a Brownian motion satisfies the Markov property. Namely, the probability of distribution for all future values of Y depends only on its current value. Applying this Property and using the trigger point Y_i^*, one can rewrite (2) as

$$\max_t E\left\{\left[V_i^T(Y) - F\right] e^{-rt}\right\} = \max_t E\left[e^{-rt}\right]\left[V_i^T(Y_i^*) - F\right]. \tag{16}$$

Following Harrison (1985) it is easy to ascertain that

$$E\left[e^{-rt_i^*}\right] = \left(\frac{Y}{Y_i^*}\right)^{\beta_1} \quad \text{for } Y < Y_i^*. \tag{17}$$

Substituting (17) into problem (16) one obtains the expected value of the opportunity to invest

$$\max_t E\left\{\left[V_i^T(Y) - F\right] e^{-rt}\right\} = \begin{cases} \left(\frac{Y}{Y_i^*}\right)^{\beta_1}\left[\frac{(1-\tau_i)Y_i^*}{\delta+\lambda} - \left(1 - \frac{\rho_i\tau_i}{r+\lambda}\right)F\right], & \text{for } Y < Y_i^*, \\ \left[\frac{(1-\tau_i)Y}{\delta+\lambda} - \left(1 - \frac{\rho_i\tau_i}{r+\lambda}\right)F\right], & \text{otherwise.} \end{cases} \tag{18}$$

Using (18), we can interpret the two conditions of Proposition 1. Let us start with the former condition. If $Y > Y_i^*$, immediate investment is the optimal strategy. According to condition 1 of Proposition 1, therefore, timing does not affect discrete choices. If $Y < Y_i^*$, the converse is true. Moreover, the expected value of the project is affected by volatility. In particular, a change in σ is twofold. On the hand it affects the expected discount factor $E\left[e^{-rt_i^*}\right]$. On the other hand, it affects the wedge $\frac{(1-\tau_i)Y_i^*}{\delta+\lambda} - \left(1 - \frac{\rho_i\tau_i}{r+\lambda}\right)F$.

It is worth noting that an increase in σ has an ambiguous effect on $E\left[e^{-rt_i^*}\right]$. First, it reduces β_1 (see Dixit and Pindyck, 1994, p. 144), thereby raising term $E\left[e^{-rt_i^*}\right]$. However, it leads to an increase in the trigger point Y_i^*. Coeteris paribus, therefore, it lowers $E\left[e^{-rt_i^*}\right]$. Thus the net effect on $E\left[e^{-rt_i^*}\right]$ is ambiguous.

The increase in σ affects the wedge $\frac{(1-\tau_i)Y_i^*}{\delta+\lambda} - \left(1 - \frac{\rho_i \tau_i}{r+\lambda}\right) F$, as well. Given the positive sign of $\frac{\partial Y_i^*}{\partial \sigma}$, the increase in σ raises the wedge $\frac{(1-\tau_i)Y_i^*}{\delta+\lambda} - \left(1 - \frac{\rho_i \tau_i}{r+\lambda}\right) F$. As the above effects have different signs, therefore, the net effect of volatility on the expected value of the opportunity to invest is ambiguous.

Finally, let us turn to condition 2 of Proposition 1. It is straightforward to show that equality $\rho_i = r + \lambda$ leads to neutrality, i.e. taxation does not affect investment timing (as $Y_i^* = \widetilde{Y}$), and the ranking between the alternative projects.

4 The measurement of the EATR

The above results have a methodological implication, concerning the measurement of the EATR. to show this let us start with Devereux and Griffith's (1998, 1999) proposal. Under exogenous timing the forward-looking effective average tax rate is

$$EATR_i = \frac{E\left[V(Y) - F\right] - \max\left\{E\left[V_i^T(Y) - F\right], 0\right\}}{E\left[V(Y) - F\right]}. \tag{19}$$

Let us now allow that firms can choose when to invest. Given rule (4), the effective average tax rate must be changed accordingly[8]:

$$EATR_i^* = \begin{cases} \frac{\max_t E\left\{\left[V(Y)-F\right]e^{-rt}\right\} - \max_t E\left\{\left[V_i^T(Y)-F\right]e^{-rt}\right\}}{\max_t E\left\{\left[V(Y)-F\right]e^{-rt}\right\}} & \text{if } Y < Y_i^* \\ \frac{E\left[V(Y)-F\right] - \max\left\{E\left[V_i^T(Y)-F\right], 0\right\}}{E\left[V(Y)-F\right]} & \text{otherwise.} \end{cases} \tag{20}$$

where the expected value of the opportunity to invest under laissez-faire

$$\max_t E\left\{\left[V(Y) - F\right] e^{-rt}\right\} = \begin{cases} \left(\frac{Y}{\widetilde{Y}}\right)^{\beta_1} \left[\frac{\widetilde{Y}}{\delta+\lambda} - F\right], & \text{for } Y < \widetilde{Y}, \\ \left[\frac{Y}{\delta+\lambda} - F\right], & \text{for } Y > \widetilde{Y}, \end{cases} \tag{21}$$

[8] The effective average tax rate can be rescaled as follows:

$$AETR_i^{*\prime} = \frac{\max_t E\left\{\left[V(Y) - F\right] e^{-rt}\right\} - \max_t E\left\{\left[V_i^T(Y) - F\right] e^{-rt}\right\}}{\max_t E\left[V(Y) e^{-rt}\right]}.$$

is obtained by setting $\rho_i = \tau_i = 0$ in the function (18). Using (14), and substituting (18) and (21) into (20) yields

$$EATR_i^* = \begin{cases} 1-(1-\tau_i)\left(\frac{1-\tau_i}{1-\frac{\rho_i\tau_i}{r+\lambda}}\right)^{\beta_1-1}, \text{ for } Y < Y_i^*, \\ 1-\frac{\frac{(1-\tau_i)Y}{\delta+\lambda}-\left(1-\frac{\rho_i\tau_i}{r+\lambda}\right)F}{\frac{Y}{\delta+\lambda}-F} \text{ otherwise.} \end{cases} \tag{22}$$

Given (22) we can thus argue that, under irreversibility, an unbiased measure of the effective average tax rate should account for the asymmetric effects of uncertainty. This result is in line with Bernanke's (1983) Bad News Principle. According to this Principle, in fact, only the bad states of nature affect the firm's intertemporal decisions. As shown by (22), in fact, only when current income is low, i.e. $Y < Y_i^*$, timing is affected. Furthermore, the effective tax burden is unaffected by current income but depends on volatility. As can be seen, in fact, the standard deviation σ affects the term $\left(\frac{1-\tau_i}{1-\frac{\rho_i\tau_i}{r+\lambda}}\right)^{\beta_1-1}$, which measures the tax distortion. It is straightforward to show that the sign of the effect of σ depends on the tax treatment of the investment cost. Easy computations show that $\frac{\partial EATR_i^*}{\partial\sigma} \propto [\rho_i - (r+\lambda)]$. If, therefore, $\rho_i > (r+\lambda)$, overinvestment takes place ($Y_i^* < \widetilde{Y}$). In this case, an increase in σ raises the $EATR_i^*$. If $\rho_i < (r+\lambda)$, the converse is true.

In the good times, instead, the tax rate proposed by Devereux and Griffith is correct. In this case, $EATR_i^*$ depends on current income. Of course, the Devereux-Griffith effective tax rate is also correct under tax neutrality[9].

5 A policy implication: wide vs. narrow tax bases

Optimal timing has also a policy implication. To analyse them, let us assume that $N = 2$. Moreover, the two alternative projects, called A and B, yield the same pre- and post-tax (positive) return, namely $V(Y) - F > 0$, and

$$V_i^T(Y) - F = \overline{E} > 0, \text{ for } i = A, B, \tag{23}$$

respectively. However, the two projects differ for the tax treatment. The former is taxed at a higher rate than the latter, i.e. $\tau_A > \tau_B$, but is

[9] In this case, setting $\rho_i = r + \lambda$ in (22) yields $EATR_i^* = EATR_i = \tau_i$.

characterised by a narrower tax base (i.e. $\rho_A > \rho_B$). This implies that, at least one of the two projects is subject to distortive taxation (i.e. $\rho_i \neq r+\lambda$).

If $Y > Y_i^*$, the value of the option is low enough. Thus, immediate investment is the optimal choice. According to condition 1 of Proposition 1, therefore, the intertemporal decision does not affect the project ranking. Moreover, given condition (23), the firm is indifferent between the two projects.

If $Y < Y_i^*$, instead, this indifference may fail. In particular, the following Proposition can be proven.

Proposition 2 *If none of the conditions of Proposition 1 holds then inequality $Y_A^* < Y_B^*$ holds.*

Proof - See the Appendix.

The intuition for Proposition 2 relies on the impact of the fiscal tools on the firm's project. It is straightforward to show that $\frac{dV_i^T(Y)}{d\tau_i} < 0$ and $\frac{dV_i^T(Y)}{d\rho_i} > 0$. Then, differentiating these derivatives with respect to Y yields $\frac{d^2V_i^T(Y)}{d\tau_i dY} < 0$ and $\frac{d^2V_i^T(Y)}{d\rho_i dY} = 0$, respectively. In other words, the lower the income Y the smaller is the impact of a tax rate change on the firm's value. To the contrary, the impact of ρ_i does not depend on Y. Given condition (23), therefore, Proposition 1 shows that, when $Y < Y_i^*$, i.e. income is relatively low, a change in ρ_i more than offsets a change in τ_i. Namely, the higher the rate ρ_i the lower is the trigger point Y_i^*. This leads to inequality $Y_A^* < Y_B^*$.

It is worth noting that inequality $Y_A^* < Y_B^*$ does not necessarily imply that project A is better than project B. Rather it just shows that the alternative projects have a different optimal timing. In order to compute the project ranking, rule (4) must be recalled. The comparison between the two alternative projects yields the following result:

Proposition 3 *If volatility is low enough, project A is preferred to project B and vice versa.*

Proof - See the Appendix.

To give the intuition behind Proposition 3, recall that volatility (i.e. σ) has an aymmetric effect on investment timing. If Y moves upward, the firm may decide to exercise the option. When, instead, Y decreases, the firm simply postpones its decision and no loss is faced[10].

[10] This is the well-known Bad News Principle, explained by Bernanke (1983).

Moreover, it can be shown that the lower the standard deviation σ, the smaller is the value of flexibility[11]. Substitute (14) and (15) into (13), so as to obtain the option value at point $Y = Y_i^*$. It is straightforward to show that $\frac{dO(Y_i^*)}{d\sigma} > 0$. In other words, the value of flexibility is positively related to σ.

Let us now turn to the choice between the two projects. Given inequality $Y_A^* < Y_B^*$, the firm is aware that choosing project A entails a tradeoff. On the one hand, the firm would earn Y earlier. On the other hand, it would lose flexibility. Given derivative $\frac{dO(Y_i^*)}{d\sigma} > 0$, the lower the standard deviation the smaller is the value of flexibility. If, therefore, σ is low enough, the loss of flexibility is more than offset by the benefit of earning Y earlier. Thus project A is preferred to project B. If σ is high, i.e. flexibility is more valuable, the converse is true.

5.1 The current debate: the ACE and CBIT proposals

The above findings have interesting policy implications. If A and B are projects offered by two different countries, according to Proposition 3, therefore, the higher-tax-rate country (i.e. country A) is preferred if σ is low enough and vice versa.

To have a clearer picture of policy implications, let us focus on two fairly innovative tax systems proposed in the 90s: the Allowance for Corporate Equity (ACE) and the Comprehensive Business Income Tax (CBIT). The former was proposed, in 1991, by the IFS Capital Taxes Group (1991). Under the ACE system, the tax base should be set equal to the firm's current earnings, net of: i) an arbitrary tax allowance for capital depreciation (not necessarily the cost of economic depreciation) and ii) the opportunity cost of finance. The ACE system is equivalent to a pure profit tax.

The CBIT was proposed by the US Treasury Department (1992). The CBIT extends the tax base at the business level by disallowing interest payments deductibility from the profit tax base. Both profits, as traditionally computed, and interest paid on debt are thus taxed at a common tax rate.

Both the proposals ensure financial neutrality. However, they have different real effects. In a closed economy, Bond (2000) argues that the ACE tax is preferable to the CBIT. In fact, the former reduces the user cost of capital under equity-financing, while leaving unchanged the tax treatment of debt. In a small economy, however, the CBIT may be preferred if differences across companies are considered. At a given level of business tax revenues,

[11] See Dixit and Pindyck (1994, Ch.6).

in fact, the ACE requires a higher statutory tax rate, since it is characterised by a narrower tax base. As a consequence, the most profitable companies (namely those earning pure profits) pay a heavier tax burden under the ACE system. If mobile multinational companies are the most profitable ones, therefore, they prefer the CBIT.

However, the above assessment disregards investment timing. To show this, let us compare a 'pure profits' tax, which has the same effects as the ACE, with the CBIT. Assume that country A implements the former, i.e. it sets $\rho_{ACE} = r + \lambda$. Using equation (14), therefore, we have $Y_A^* = \widetilde{Y}$.

Country B, instead, introduces the CBIT, namely it sets $\rho_{CBIT} = \lambda$. Since the tax system is characterised by a wider tax base, in order for the same amount of tax revenues to be raised, inequality $\tau_{ACE} > \tau_{CBIT}$ holds. Following Bond (2000), therefore, high-income firms would prefer country B. When investment timing is optimally chosen, however, a tradeoff takes place. On the one hand, at any given time, high-income firms pay a heavier tax burden under the ACE system. On the other hand, inequality $Y_{ACE}^* = \widetilde{Y} < Y_{CBIT}^*$ holds. This implies that companies choosing country A start to earn profits earlier than companies investing in the CBIT country. Given this offsetting effect, the ranking between the two systems may be reversed. In particular, if $Y < Y_{ACE}^* < Y_{CBIT}^*$, according to Proposition 3, the ACE system would be preferred to the CBIT one, if volatility is low enough.

To make this point clearer we propose the following example. Given inequality $\rho_{ACE} = r + \lambda > \rho_{CBIT} = \lambda$, let us set $\tau_{CBIT} = 0.31$, which is the rate suggested in 1992 by the US Treasury. Moreove, assume that: $r = 0.06$, $\lambda = 0.10$, $\delta = 0.04$, $F = 100$ and $Y = 18.2$. Under exogenous timing, the ACE tax rate ensuring the same post-tax return as that earned under the CBIT (i.e. ensuring condition (23) to hold) is $\tau_{ACE} = 0.48096$. Although this rate is more than 17 percentage points higher than the CBIT one, the ACE system can be preferred by a multinational under endogenous timing. Using Proposition 3, it is straightforward to show that the ACE country is preferred to the CBIT one if volatility is less than a failry high threshold level, i.e. 0.30754. This result suggests how the debate on tax design should account for timing.

6 Conclusion

In this paper we have shown that taxation may affect investment timing. In turn, timing may affect discrete investment choices. This chain of causality has both methodological and policy implications. The former regards the computation of the EATR. Under endogenous timing we have shown that the EATR should account for the asymmetric effects of uncertainty on investment timing.

As to policy implications, it is worth noting that one of the crucial points of the EU debate on tax co-ordination regards the implementation of a common tax base. As argued in the recent Report of the EU Commission Services Study on 'Company Taxation in the Internal Market' (2001), 'only providing multinational companies with a consolidated corporate tax base for the EU-wide activities will really ... tackle the majority of the tax obstacls to cross-border economic activity in the Single Market' (Executive Summary, p. 15). As we have shown, a wide-tax-base system may be less desirable under endogenous timing.

Both the statistical significance of this methodological point and the implementation of sensitivity analysis for policy options are left to future research.

7 Appendix

7.1 Computation of the project's function

To compute the firm's value, let us start with the Bellman function (11). Using Itô's Lemma, eliminating all the terms multiplied by $(dt)^2$ and dividing by dt yields

$$(r+\lambda)V_i^T(Y) = Y_i^T + (r-\delta)Y\frac{\partial V_i^T(Y)}{\partial Y} + \frac{\sigma^2}{2}Y^2\frac{\partial^2 V_i^T(Y)}{\partial Y^2} \tag{24}$$

Using standard techniques[12], it can be shown that (24) has the following closed-form solution

$$V_i^T(Y) = \frac{(1-\tau_i)Y}{\delta+\lambda} - \frac{\rho_i\tau_i}{r+\lambda}F + \sum_{i=1}^{2} A_i Y^{\beta_i}, \tag{25}$$

where

$$\begin{aligned}\beta_1 &= \tfrac{1}{2} - \tfrac{r-\delta}{\sigma^2} + \sqrt{\left(\tfrac{1}{2} - \tfrac{r-\delta}{\sigma^2}\right)^2 + \tfrac{2(r+\lambda)}{\sigma^2}} > 1,\\ \beta_2 &= \tfrac{1}{2} - \tfrac{r-\delta}{\sigma^2} - \sqrt{\left(\tfrac{1}{2} - \tfrac{r-\delta}{\sigma^2}\right)^2 + \tfrac{2(r+\lambda)}{\sigma^2}} < 0.\end{aligned}$$

[12] The reader will find further details on these computations in Dixit and Pindyck (1994, Ch. 5 and 6).

are the positive and negative roots of the characteristic equation

$$\frac{\sigma^2}{2}\beta(\beta-1)+(r-\delta)\beta-(r+\lambda)=0,$$

respectively. Let the boundary condition $V(0)=0$ hold. This condition implies that if Y goes to zero, it will stay at zero[13]. If this is true, then A_2 must be null. Moreover, assume that if Y goes to infinity, no financial bubbles exist. This condition implies that the parameter A_1 must be nil. Given the above boundary conditions, we obtain function (12).

7.2 Proof of Proposition 2

Let us differentiate the net present value of the firm's project $\left[V_i^T(Y)-F\right]$ with respect to the tax instruments. Using the value function (12) yields

$$d\left[V_i^T(Y)-F\right]=-\left[\frac{Y}{\delta+\lambda}-\frac{\rho_i}{r+\lambda}F\right]d\tau_i+\left(\frac{\tau_i}{r+\lambda}F\right)d\rho_i. \tag{26}$$

Using (26), setting $d\left[V_i^T(Y)-F\right]=0$, and solving for $d\rho_i$ yields

$$d\rho_i=\frac{\frac{Y}{\delta+\lambda}-\frac{\rho_i}{r+\lambda}F}{\frac{\tau_i}{r+\lambda}F}d\tau_i, \tag{27}$$

i.e. $\frac{d\rho_i}{d\tau_i}\propto\left(\frac{Y}{\delta+\lambda}-\frac{\rho_i}{r+\lambda}F\right)$. Next, differentiate the trigger point Y_i^* with respect to the tax instruments

$$dY_i^*=\widetilde{Y}\left\{\left[\frac{1-\frac{\rho_i}{r+\lambda}}{(1-\tau_i)^2}\right]d\tau_i-\frac{\tau_i}{1-\tau_i}\frac{1}{r+\lambda}d\rho_i\right\}. \tag{28}$$

Substituting (27) into (28) and using condition (23) one obtains

$$\frac{dY_i^*}{d\tau_i}=-\frac{\widetilde{Y}}{F}\frac{1}{(1-\tau_i)^2}\overline{E}<0. \tag{29}$$

Given (29), it can be shown that $(Y_A^*-Y_B^*)\propto(\tau_B-\tau_A)$. Proposition 2 is thus proven.■

[13]For further details on this absorbing barrier see Harrison (1985, Ch. 3).

7.3 Proof of Proposition 3

Substitute function (18) into problem (2). Project A is preferred to project B if

$$\left(\frac{Y}{Y_A^*}\right)^{\beta_1}\left[\frac{(1-\tau_A)Y_A^*}{\delta+\lambda}-\left(1-\frac{\rho_A\tau_A}{r+\lambda}\right)F\right]>\left(\frac{Y}{Y_B^*}\right)^{\beta_1}\left[\frac{(1-\tau_B)Y_B^*}{\delta+\lambda}-\left(1-\frac{\rho_B\tau_B}{r+\lambda}\right)F\right]. \quad (30)$$

Using the trigger point (14), inequality (30) can be rewritten as

$$R(\sigma)>1, \quad (31)$$

where

$$R(\sigma)\equiv\left[\frac{\left(1-\frac{\rho_B\tau_B}{r+\lambda}\right)/(1-\tau_B)}{\left(1-\frac{\rho_A\tau_A}{r+\lambda}\right)/(1-\tau_A)}\right]^{\beta_1-1}\left(\frac{1-\tau_A}{1-\tau_B}\right)$$

is a continuously differentiable function of σ. Compute now the log-transform of $R(\sigma)$

$$\log R(\sigma)\equiv(\beta_1-1)\log\left[\frac{\left(1-\frac{\rho_B\tau_B}{r+\lambda}\right)/(1-\tau_B)}{\left(1-\frac{\rho_A\tau_A}{r+\lambda}\right)/(1-\tau_A)}\right]+\log\left(\frac{1-\tau_A}{1-\tau_B}\right).$$

Using function (12) and condition (23) one can show that

$$\frac{\overline{E}}{1-\tau_A}+\frac{1-\frac{\rho_A\tau_A}{r+\lambda}}{1-\tau_A}F=\frac{Y}{\delta+\lambda}=\frac{\overline{E}}{1-\tau_B}+\frac{1-\frac{\rho_B\tau_B}{r+\lambda}}{1-\tau_B}F.$$

Since $\tau_A>\tau_B$, then we have

$$\frac{\overline{E}}{1-\tau_A}-\frac{\overline{E}}{1-\tau_B}=\frac{1-\frac{\rho_B\tau_B}{r+\lambda}}{1-\tau_B}F-\frac{1-\frac{\rho_A\tau_A}{r+\lambda}}{1-\tau_A}F>0.$$

Given the above inequality, one can show that $\frac{\left(1-\frac{\rho_B\tau_B}{r+\lambda}\right)/(1-\tau_B)}{\left(1-\frac{\rho_A\tau_A}{r+\lambda}\right)/(1-\tau_A)}>1$. Thus differentiating $\log R(\sigma)$ with respect to β_1 yields $\frac{\partial\log R(\sigma)}{\partial\beta_1}>0$. Moreover, we know that $\frac{\partial\beta_1}{\partial\sigma}<0$[14]. Thus we obtain

$$\frac{\partial\log R(\sigma)}{\partial\sigma}=\frac{\partial\log R(\sigma)}{\partial\beta_1}\cdot\frac{\partial\beta_1}{\partial\sigma}<0.$$

[14] See Dixit and Pindyck, 1994, p. 144.

Next, let us compute the following

$$\lim_{\sigma\to+\infty} R(\sigma) = \frac{1-\tau_A}{1-\tau_B} < 1,$$
$$\lim_{\sigma\to 0} R(\sigma) = +\infty.$$

By invoking the Brouwer Fixed-Point Theorem (see Varian, 1992, p. 195), there exists one value of σ, called σ^*, such that $R(\sigma^*) = 1$. We thus obtain $[R(\sigma) - 1] \propto (\sigma^* - \sigma)$. This relationship implies that, if $\sigma < \sigma^*$, project A is preferred to project B, and vice versa. Proposition 3 is thus proven.■

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