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WORKING PAPERS

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THE ROLE OF CORPORATE TAX ASYMMETRIES IN A CONTINUOUS-TIME MODEL WITH DEPRECIATION

Brescia, aprile 2000

The Role of Corporate Tax Asymmetries in a Continuous-Time Model with Depreciation*

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April 2000

Abstract

This article discusses the effects of corporate tax asymmetries under investment irreversibility, by extending the results of Panteghini (2000b). I.in particular, we use a time-continuous model with income uncertainty. Moreover, we assume that the firm's shareholders may be risk-averse and that investment depreciates. Finally, we introduce policy uncertainty on future tax rates. Despite these generalisations, neutrality, with respect not only to income uncertainty but also to policy uncertainty, still holds.

JEL classification: H25; keywords: corporate taxation, irreversibility, neutrality, uncertainty.

*The author is grateful to Gianni Amisano, Paul Anglin, Massimo Bordignon, Michael Devereux, Tomas Forsfält, Antonio Guccione, Vesa Kanniainen, Fulvio Ortu, Wolfgang Runggaldier and Hans-Werner Sinn for helpful comments and suggestions. He accepts responsibility for any remaining errors.

1. Introduction

A recent strand of research has been studying corporate taxation under investment irreversibility[1] (see e.g. McKenzie (1994), Alvarez and Kanniainen (1997, 1998), and Faig and Shum (1998)). The main results obtained by this literature show that investment irreversibility amplifies the distortions caused by corporate taxation. As shown by Panteghini (2000b), this is not necessarily true. In fact, the tax systems analysed in the above articles were originally designed for fully reversible investment, where the bad and good states of nature affect the firms' decisions symmetrically. When investment is irreversible, instead, due to the well-know Bernanke's (1983) Bad News Principle, only the bad state affects investment. Thus, the asymmetric effects of uncertainty may coexist with an asymmetric treatment of profits and losses, thereby obtaining neutrality.

In Panteghini (2000b) we presented a tax system which is similar to that proposed by Garnaut and Ross (1975). Namely the tax base is given by the firm's return net of an imputation rate. Contrary to the Garnaud-Ross proposal, however, when the firm's return is less than the imputation rate, no tax refunds are allowed. Under this scheme, firms undertake investment when profitability is relatively low and current taxation is null. Since only future taxation matters, this tax design is neutral with respect to policy uncertainty as well.

The aim of this article it to extend the results of the above companion paper. Firstly, instead of vanishing after one period, uncertainty is assumed to last until the project fully depreciates. It is worth noting that the introduction of a depreciation rate allows us to deal with partial reversibility[2].

The second extension regards the introduction of risk-aversion. In the fashion of McDonald and Siegel (1985, 86), we assume that the risk-neutral firm under

[1] As argued by Dixit and Pindyck (1994, p.3) 'Most investment decisions share three important characteristics, investment irreversibility, uncertainty and the ability to choose the optimal timing of investment'. As we know, investment irreversibility may arise from 'lemon effects', and from capital specificity (see Dixit and Pindyck, 1994, and Trigeorgis, 1996). Even when brand-new capital can be employed in different productions, in fact, it may become specific once installed. Irreversibility may be caused by industry comovement as well: when a firm can resell its capital, but the potential buyers operating in the same industry are subject to the same market conditions, this comovement obliges the firm to resort to outsiders. Due to reconversion costs, however, the firm can sell the capital at a considerably low price than an insider would be willing to pay if it did not face the same bad conditions as the seller.

[2] When the investment project expires, in fact, the firm is endowed with an option to restart. But the firm is not obliged to restart immediately. Rather, it may wait until profits will rise. With such an option to restart, therefore, the firm regains a degree of freedom in managing its investment strategy.

study may be owned by risk-averse shareholders.

Thirdly, policy uncertainty is designed as a Poisson process, so that future tax rates are neither known nor certain.

Despite the above generalisations, neutrality with respect not only to income uncertainty but also to policy uncertainty still holds.

This article is structured as follows. Section 2 briefly discusses the related literature on tax asymmetries and irreversibility. Section 3 introduces a simple continuous-time model where uncertainty lasts to infinity and derives the sufficient neutrality condition. Section 4 introduces the Garnaut-Ross proposal and its modified version without refundability. In sections 5 both policy uncertainty and depreciation are modelled as Poisson processes. As will be shown, neutrality still holds. In section 6, we propose a numerical example. Finally, section 7 summarises the results and discusses their implications.

2. The related literature

In the existing literature on corporate taxation, the neutrality results are based on quite restrictive assumptions[3]. Namely, neutrality holds provided that: a) the treatment of profits and losses is symmetric, and b) the statutory tax rate is known and constant.

Unfortunately, these conditions are difficult to implement. The symmetry condition a) fails because of the possibility of fraudulent losses. Moreover, the symmetry device may require negative tax payments to expanding firms as well. As argued by Isaac (1997) "...there is both survey and anedoctal evidence that both governments and companies commonly place considerably more value on cash flow than is measured by conventional NPV arithmetic" [pp. 308-9][4].

[3]The modern literature on corporate taxation is based on the contribution of Boadway and Bruce (1984), who proposed 'a simple and general result on the design of a neutral and inflation-proof business tax' [p. 232]. According to this rule, the business tax base is given by the firm's current earnings, net of the accounting depreciation rate (applied to the accounting capital stock) and of the nominal cost of finance. Fane (1987) finds that the Boadway and Bruce (1984) general neutrality principle holds even under uncertainty, provided that the tax credit and liabilities are certainly redeemed and that the tax rate is known and constant. Recently, Bond and Devereux (1995) have proven that a business tax scheme, based on the Boadway-Bruce Principle, is neutral even when income, capital and bankruptcy risk are introduced. They have also proven that the imputation rate ensuring neutrality remains the nominal interest rate on default-free bonds. For further details see Panteghini (2000a,b).

[4]A similar critique is also contained in Auerbach (1986), who argues that the utilisation of carryforward or carrybackward devices is distortive: "While the high probability of a tax loss may discourage the low-return firm from investing initially, once the investment is sunk and, with

Similarly, condition b) is hard to implement. If future tax rates are neither known nor constant, neutrality fails to hold. But, as argued by Sandmo (1979), "academic discussions of tax reform in a world of unchanging tax rates is something of a contradiction in terms" [p. 176].

Note that policy uncertainty may imply a time inconsistency as well. In fact, firms which have paid an investment cost may be taxed at a higher rate for the profits produced with the installed capital. Since firms are aware of this possibility, they can decide to reduce investment (see e.g. Nickell (1977, 78) and Mintz (1995)), unless the government precommits itself.

Finally, it must also be noted that most of the existing literature (see e.g. Boadway and Bruce (1984), Fane (1987), and Bond and Devereux (1995)) *implicitly* assumes that investment is fully reversible. Namely, investment can be resold without any additional cost. On the contrary, empirical evidence shows that investment is, at least, partially irreversible (see e.g. Guiso and Parigi, 1999).

For this reason, in the last decade, some tax economists studied the interactions between, on the one hand, irreversibility, uncertainty and investment timing, and, on the other hand, corporate taxation[5]. They concluded that, under investment irreversibility, the more asymmetric the tax system, the more distortive is corporate taxation.

So far, it is not clear whether policy uncertainty stimulates or discourages irreversible investment. Irrespective of the sign of effect, however, the existing literature considers policy uncertainty as an additional source of distortions. In particular, Hassett and Metcalf (1994, 1995) show that the effects of tax policy on the investment decisions depend on the characteristics of the tax policy change. If the tax policy follows a Brownian motion (i.e. a continuous random walk) the

some probability, the tax loss occurs, further investment decisions will be made taking account of the loss carryforward. Since such accumulated tax losses decay in value over time, firms may increase their investment to use them up [...] A "loser" may suffer more from the absence of a loss offset but may also be more likely to accelerate investment to use up loss carryforwards" [p. 206].

[5]A pioneering article dealing with irreversibility is that of MacKie-Mason (1990), who shows that, under non-refundability, the corporation tax always reduces the value of the investment project. Moreover, Alvarez and Kanniainen (1997, 1998) show that, under irreversibility, the Johansson-Samuelson theorem fails to hold. Faig and Shum (1999) confirm the above results. In particular, they find that the higher the degree of irreversibility, the more distortive is a corporate tax system. Furthermore, distortions are amplified by tax asymmetries. Finally, Pennings (2000) shows that a combination of a lump-sum subsidy with a symmetric profits tax stimulates irreversible investment even if the expected tax revenues are null. Some authors also studied the effects of irreversibility on some existing tax schemes (see e.g. McKenzie (1994) for the Canadian corporate tax system and Zhang (1997) for the British Petroleum Revenue Tax).

firm's trigger point is increased, and investment is postponed[6]. If, conversely, tax policy is described by a Poisson process, namely with discrete changes, the firm's trigger point is reduced and investment is stimulated. In this article we will choose this latter modelisation since evidence shows that tax parameters may remain constant for a long period and, then, suddenly jump.

3. The model

In this section we introduce a continuous-time model describing the behaviour of a competitive risk-neutral firm. Using a standard optimal stopping time model, we study the firm's investment decisions under irreversibility. Then, we introduce taxation, and derive a sufficient neutrality condition.

The model and the notation are those of Dixit and Pindyck (1994, Ch. 2). In particular, the following hypotheses hold:

i) risk is fully diversifiable;

ii) the risk-free interest rate r is fixed;

iii) there exists an investment cost I.

In the fashion of McDonald and Siegel (1985, 86), moreover, we assume that:

iv) the firm is risk-neutral, but its owners may be risk-averse;

v) current gross profits follow a geometric Brownian motion

$$d\Pi(t) = \alpha\Pi(t)dt + \sigma\Pi(t)dz$$

where α and σ are the growth rate and variance parameter, respectively. Given the dividend rate δ (which must be positive in order for the net value of the firm to be bounded), if the shareholders are risk-neutral, the difference $r - \delta$ is equal to α. If, conversely, the shareholders are risk-averse, the difference $r - \delta$ takes account of a the risk premium[7].

[6] This result is a direct implication of Pindyck's (1988) findings. See also Aizenman (1996), who uses a general equilibrium model with uncertain jumps in the tax rate. He shows that this kind of policy uncertainty discourages investment. Note also that Cummins, Hassett and Hubbard (1994, 1995, 1996) find evidence of statistically significant investment responses to tax changes in 12 of the 14 countries.

[7] According to the Intertemporal Capital Asset Pricing Model, in fact, the total expected rate of return $\mu = \delta + \alpha$ must satisfy the relationship $\mu = r + \lambda\sigma\rho_M$ where $\lambda \equiv (\mu_M - r)/\sigma_M$ is the market price of risk, with parameters μ_M, σ_M^2 and ρ_M representing the expected return, the variance of the market portfolio and the correlation coefficient between the rate of return on the asset and that on the portfolio, respectively. Under risk aversion, therefore, the equality $r - \delta = \alpha - \lambda\sigma\rho_M$ holds. As shown in Merton (1990, Ch. 15), the risk-adjusted drift $\alpha - \lambda\sigma\rho_M$ allows the valuation of the firm as if it were risk neutral.

Thus, the firm chooses its optimal investment timing by using the Value Matching Condition (VMC) and the Smooth Pasting Condition (SPC). The former condition requires that the present value of the project (net of the investment cost) is equal to the option to delay investment, namely

$$[II.1]\ V(\Pi) - I = O(\Pi),$$

The latter condition requires the slopes of the functions $V(\Pi) - I$ and $O(\Pi)$ to match[8]

$$[II.2]\ \frac{\partial}{\partial \Pi}(V(\Pi) - I) = \frac{\partial O(\Pi)}{\partial \Pi}.$$

3.1. The sufficient neutrality condition

When taxation is introduced, the sufficient neutrality condition requires that all the costs are deductible. As argued by Niemann (1999), in fact, ignoring the deduction of the opportunity cost would overstate the option value, thereby discouraging immediate investment (see also Richter, 1986 and Panteghini, 2000b).

Given a generic tax rate τ, when the option value is deductible, the net value of the project is $(1-\tau)$ times the pre-tax value, namely $(1-\tau)\cdot[V(\Pi) - I - O(\Pi)]$. Following this neutrality condition, the VMC and the SPC are

$$[II.1']\ (1-\tau)\cdot[V(\Pi) - I - O(\Pi)] = 0,$$

$$[II.2']\ (1-\tau)\cdot\frac{\partial}{\partial \Pi}\{(V(\Pi) - I - O(\Pi)\}\,|_{\Pi=\Pi^*} = 0.$$

In this case, the tax rate does not affect the investment decision. This neutrality result can be explained as follows. On the one hand, an increase (decrease) in the tax rate reduces (raises) the present value of future discounted profits and induces the firm to delay (anticipate) investment. On the other hand, the increase (decrease) in the tax rate causes a decrease (an increase) in the option value, namely in the opportunity cost of investing at time 0, thereby encouraging (discouraging) investment. If conditions $[II.1']$ and $[II.2']$ hold, these offsetting effects neutralise each other.

[8] For further details on these two conditions see Dixit and Pindyck (1994, Ch. 5).

4. The Garnaut-Ross proposal and its modification

Once we have derived the neutrality condition, let us now study the effects of tax refunding. To do so we use two alternative imputation systems[9]. The first system is similar to that proposed by Garnaut and Ross (1975). Namely, the tax base is given by the firm's return, net of an imputation rate. This system is symmetric: namely, when the firm's return is less than the imputation rate, full tax refunds are allowed.

The second system is based on the same imputation method. However, it allows no tax refunds when the firm's return is less than the imputation rate[10].

When taxation is introduced, net instantaneous profits (or losses) are equal to

$$\Pi^N(t) = \begin{cases} \Pi(t) - \tau\left[\Pi(t) - r_E I\right] & \text{if full refundability is allowed;} \\ \Pi(t) - \tau \max\left[\Pi(t) - r_E I, 0\right] & \text{if non-refundability holds.} \end{cases}$$

Using the dynamic programming approach, the firm's value can be written as

$$[IV.1] \quad V(\Pi(t)) = \Pi^N(t)dt + e^{-rdt}E\left[V(\Pi(t) + d\Pi(t))\right].$$

Expanding the right-hand side of $[IV.1]$ and using Itô's lemma one obtains

$$[IV.1'] \quad rV(\Pi(t)) = \Pi^N(t) + (r-\delta)\Pi V_\Pi + \frac{\sigma^2}{2}\Pi^2 V_{\Pi\Pi}$$

where $V_\Pi = \partial V(\Pi)/\partial\Pi$ and $V_{\Pi\Pi} = \partial^2 V(\Pi)/\partial\Pi^2$, respectively. For simplicity, hereafter, we will omit the time variable t.

Under full refundability, equation $[IV.1']$ has the following solution

$$[IV.2] \quad V(\Pi) = V^*(\Pi) - \tau\left[V^*(\Pi) - \frac{r_E}{r}I\right]$$

where $V^*(\Pi) = \Pi/\delta$ is the laissez-faire present value of expected future gross profits and $\tau\left[V^*(\Pi) - \frac{r_E}{r}I\right]$ is the present value of future tax payments. Note

[9] In the Nineties, dual tax systems of corporate taxation (based on the imputation method) were introduced in the Nordic countries (see Sørensen, 1998), and in Italy (see Bordignon et al., 2000). Moreover, the Allowance for Corporate Equity (ACE), proposed by the IFS Capital Taxes Group (1991) for the British tax system, can be considered as a special case of the above dual tax systems, where the lower tax rate is null. As we know, a form of ACE taxation was adopted in Croatia in 1994, under the name of Interest Adjusted Income Tax (see Rose and Wiswesser (1998)).

[10] Note that both effective and opportunity costs are deductible and, thus, both the tax systems studied do not distort financial decisions.

that term $\tau\frac{r_E}{r}I$ measures the present discounted value of the tax benefit due to the deductible opportunity cost.

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

$$O(\Pi) = H_R \Pi^{\beta_1}$$

where H_R is an unknown parameter to be determined. Under the assumptions that no financial bubbles exist, and that $V(0) = 0$, we combine the VMC and the SPC to compute the trigger point above which entry is profitable

$$[IV.3] \quad \Pi^* = \frac{\beta_1}{\beta_1 - 1} \cdot \frac{1 - \frac{r_E}{r}\tau}{1 - \tau} \cdot \delta I.$$

The option value multiple $\frac{\beta_1}{\beta_1 - 1}$ shows that the gross present discounted value $V^*(\Pi)$ must exceed the investment cost to compensate for investment irreversibility. As can be seen, setting $r_E = r$, the trigger point is equal to the laissez-faire one (namely the trigger point with a null tax rate τ)

$$\Pi^* = \frac{\beta_1}{\beta_1 - 1} \cdot \delta I.$$

Therefore, the neutrality results found by Fane (1987) and Bond and Devereux (1995) hold even under irreversibility[11].

Turn next to the non-refundability system. Using condition $[IV.1']$ the value of the investment project is

$$[IV.4] \quad V(\Pi) = \begin{cases} V^*(\Pi) + A_1 \Pi^{\beta_1} & \text{if} \quad \Pi < r_E I \\ (1-\tau)V^*(\Pi) + B_2 \Pi^{\beta_2} + \tau\frac{r_E}{r}I & \text{if} \quad \Pi > r_E I \end{cases}$$

Applying the VMC and SPC at point $\Pi = r_E I$ we make the two branches of function $[IV.4]$ meet tangentially and find

$$\begin{aligned} A_1 &= -\tau \cdot \frac{r - \beta_2(r-\delta)}{(\beta_1 - \beta_2) r\delta} \cdot (r_E I)^{1-\beta_1}, \\ B_2 &= -\tau \cdot \frac{r - \beta_1(r-\delta)}{(\beta_1 - \beta_2) r\delta} \cdot (r_E I)^{1-\beta_2}. \end{aligned}$$

[11] Note that, under interest rate uncertainty, instead, the neutral imputation rate depends on the nature of investment. As shown by Panteghini (2000a), if investment is reversible, the imputation rate ensuring neutrality is proportional to the short-term interest rate on default-free bonds. If, instead, investment is irreversible, the rate r_E must be higher, in order to compensate for the discouraging effects of irreversibility.

Both terms $A_1\Pi^{\beta_1}$ and $B_2\Pi^{\beta_2}$ are negative. The former represents the present discounted value of future tax payments if current profits are less than the opportunity cost. The latter measures the present discounted value of the loss due to the lack of refundability, if current profits are greater than the opportunity cost.

The decision to invest is derived from the comparison of the net present value of the profits flow $[V(\Pi) - I]$ with the option function

$$[IV.5] \quad O(\Pi) = H_{NR}\Pi^{\beta_1}$$

where H_{NR} is an unknown parameter. The following proposition can easily be proven.

Proposition 1- *Under the assumption that current gross profits follow a geometric Brownian motion, if* $r_E \geq r_E^* \equiv \frac{\beta_1}{\beta_1 - 1} \cdot \delta$, *the non-refundability regime is neutral.*

Proof. As proven by Panteghini (2000b), to obtain neutrality it is sufficient for the investing firm to benefit from a sufficiently generous tax holiday (see Garnaut and Ross (1975)). Namely, given the current payoff Π_0, the imputation rate must be sufficiently high

$$[IV.6] \; r_E \geqslant \Pi_0/I$$

To prove that the above condition ensures neutrality, we must use the VMC and SPC. If inequality [IV.6] holds, the VMC and SPC are given by equations [II.1] and [II.2], i.e. the laissez-faire conditions. Given the above conditions, one thus obtains the trigger point $\Pi^* = [\beta_1/(\beta_1 - 1)]\,\delta I$,and parameter $H_{NR} = A_1 + (\frac{\Pi^*}{\delta} - I) \cdot \Pi^{*-\beta_1}$. Of course, point Π^* is unaffected by taxation.

Now, let us compute the minimum imputation rate ensuring neutrality. To do so it is sufficient to substitute the laissez-faire point Π^* into condition $[IV.6]$, thereby obtaining $r_E \geq r_E^* \equiv \frac{\beta_1}{\beta_1 - 1} \cdot \delta$. The Proposition is thus proven. ■

Note that Proposition 1 does not imply that the present value of the project $V(\Pi)$ is unaffected by the corporation tax. As can be noted, in fact, an increase in the tax rate reduces the present value of future discounted profits and induces the firm to delay investment. However, the decrease in the project value is offset by a decrease in the option value since the higher the tax rate the lower the opportunity cost and, consequently, the higher the incentive to invest. Neutrality takes place,when the net result of the above effects is null[12].

[12] If $\Pi \leq r_E I$, in fact, we have $\frac{\partial V(\Pi)}{\partial \tau} = \frac{\partial O(\Pi)}{\partial \tau} = \frac{\partial A_1}{\partial \tau} \cdot \Pi^{\beta_1}$.

According to Proposition 1, when an asymmetric tax device is introduced, the elimination of a tax benefit (i.e. the loss-offset arrangement) must be compensated with the introduction of a new benefit (namely a higher imputation rate) in order for neutrality to hold. This result is not novel at all: Ball and Bowers (1983) and Auerbach (1986) found similar results. However, they implicitly assumed fully reversible investment, and this assumption implied the computation of an ad hoc value of r_E. Unfortunately, this procedure was too informationally demanding, since the firm-specific riskiness had to be known.

Under irreversibility, instead, we can derive an entire region of neutral imputation rates, i.e. $r_E \in [r_E^*, \infty)$[13]. Therefore, it is sufficient to set a rate r_E sufficiently high for obtaining neutrality, without any further complication regarding the choice of ad hoc imputation rates for each sector or firm.

The result of Proposition 1 can be explained by recalling van Wijnbergen and Estache (1999). Following Domar and Musgrave (1944), they argue that the corporate tax is equivalent to equity participation. When the losses are non-refundable, however, the government is also endowed with a *put option with strike price zero* written on the firm's profits (p.81). If, namely, the firm's return drops below $r_E I$, the government benefits from the non-refundable arrangement. Thus, it acts as if it sold its equity participation at price zero, and it does not share any losses. The government's participation will then be rebought (at price zero) when the firm faces a positive result.

The interpretation of van Wijnbergen and Estache (1999) is helpful to explain why we obtain a set of neutral imputation rates instead of a single value. In the $r_E \in [r_E^*, \infty)$ region, in fact, the effects of an increase in the imputation rate are twofold. On the one hand, the government's equity participation decreases (namely the expected tax burden decreases). On the other hand, the value of the government's put option increases (namely, the non-refundability arrangement is more valuable). These two effects neutralise each other.

5. Policy uncertainty and depreciation

In this section we study the effects of policy uncertainty on investment decisions. As we know, under irreversibility, policy uncertainty may imply a time

[13]Note that inequality $r_E^* > r$ always holds. Under the non-refundability system, therefore, the differential $r_E^* - r$ is sufficient to neutralise the effects of the asymmetric treatment of profits and losses.

inconsistency[14]. In particular, the effects of policy uncertainty are twofold. On the one hand, the government may announce a tax rate change which is not implemented after (i.e. the tax rate is unknown but remains constant). On the other hand, an unexpected tax change may take place (i.e. the tax rate is unknown and variable). In both cases, firms would become aware that the government may undertake actions different from those initially planned and would try to anticipate the government's choices. As will be shown, the inconcistency problem vanishes if the asymmetric tax device is employed.

To complete the analysis and make it more realistic we also introduce depreciation. This implies that the firm is now endowed with a limited degree of reversibility. When the investment project expires, therefore, the firm gets an option to restart. But immediate restarting may not be profitable, and the firm may find it convenient to wait until profits will rise. Both policy uncertainty and depreciation are modelled as Poisson processes.

Proposition 2 - *Under the following assumptions*
i) The lifetime of investment follows a Poisson process, namely at any time t there is a probability $\lambda_1 dt$ that the existing project dies during the short internal dt.
ii) If the project dies, the firm gets the original opportunity to invest back again (see Dixit and Pindyck (1994), p.210)
iii) The tax rate τ follows a Poisson process

$$d\tau = \begin{cases} 0 & \text{w.p.} \quad 1-\lambda_2 dt \\ \Delta\tau & \text{w.p.} \quad \lambda_2 dt \end{cases}$$

where $\Delta\tau = \tau_{new} - \tau_{old}$ (irrespective of the sign of the differential $\tau_{new} - \tau_{old}$) neutrality holds on condition that the rate of relief is sufficiently high, namely

$$\Pi^{*'} = \frac{\beta_1(\lambda_1)}{\beta_1(\lambda_1)-1}(\delta+\lambda_1)I.$$

Proof. Following Proposition 1, we concentrate on the $[0, r_E I]$ region, with $r_E \geqslant \frac{\Pi^{*'}}{I}$, where the trigger point $\Pi^{*'}$ must be computed.

Define now $O_0(\Pi)$ and $O_1(\Pi)$ as the option functions before and after the reform, respectively. Similarly, $V_0(\Pi)$ and $V_1(\Pi)$ are the pre- and post-reform value functions, respectively.

[14]As argued by Mintz (1995), "When capital is sunk, governments may have the irresistible urge to tax such a capital at a high rate in the future. This endogeneity of government decisions results in a problem of *time consistency* in tax policy whereby governments may wish to take actions in the future that would be different from what would be originally planned..." [p.61].

Let us start with the option functions. Note that the option functions are not affected by λ_1 (the depreciation rate), whereas policy uncertainty affects both the option function and the value function. Thus we have

$$[V.1] \quad O_0(\Pi) = e^{-rdt}\left\{\lambda_2 dt\xi\left[O_1(\Pi + d\Pi)\right] + (1-\lambda_2 dt)\xi\left[O_0(\Pi + d\Pi)\right]\right\}$$

and

$$[V.2] \quad O_1(\Pi) = e^{-rdt}\left\{\xi\left[O_1(\Pi + d\Pi)\right]\right\}.$$

Let us now turn to the value functions. Given assumption ii), over the range $\Pi < \Pi^{*'}$, if the project dies, the firm regains the right to start another (identical) project, but it postpones reinvestment. Thus, the value functions can be written using the dynamic programming as[15]

$$\begin{aligned}[V.3] \quad V_0(\Pi) \;&=\; \Pi dt + e^{-rdt}\left\langle(1-\lambda_1 dt)\left\{\lambda_2 dt\xi\left[V_1(\Pi + d\Pi)\right] + (1-\lambda_2 dt)\xi\left[V_0(\Pi + d\Pi)\right]\right\}\right\rangle + \\ &\quad + e^{-rdt}\lambda_1 dt\left\{\lambda_2 dt\xi\left[O_1(\Pi + d\Pi)\right] + (1-\lambda_2 dt)\xi\left[O_0(\Pi + d\Pi)\right]\right\}\end{aligned}$$

and

$$[V.4] \quad V_1(\Pi) = \Pi dt + e^{-rdt}\left\{(1-\lambda_1 dt)\xi\left[V_1(\Pi + d\Pi)\right] + \lambda_1 dt\xi\left[O_1(\Pi + d\Pi)\right]\right\}.$$

Over the range $\Pi > \Pi^{*'}$, instead, if the current project dies, immediate investment is profitable. In this case we have

$$\begin{aligned}V_0 \;&=\; \Pi dt + e^{-rdt}\left\langle(1-\lambda_1 dt)\left\{\lambda_2 dt\xi\left[V_1(\Pi + d\Pi)\right] + (1-\lambda_2 dt)\xi\left[V_0(\Pi + d\Pi)\right]\right\}\right\rangle + \\ &\quad + \lambda_1 dt\left\{\lambda_2 dt\xi\left[O_1(\Pi + d\Pi)\right] + (1-\lambda_2 dt)\xi\left[O_0(\Pi + d\Pi)\right] - I\right\}\end{aligned}$$

and

$$V_1(\Pi) = \Pi dt + e^{-rdt}\left\{(1-\lambda_1 dt)\xi\left[V_1(\Pi + d\Pi)\right] + \lambda_1 dt\xi\left[O_1(\Pi + d\Pi) - I\right]\right\}.$$

The two branches of the value function must meet tangentially at the common point $\Pi^{*'}$. Therefore we can use either branch for the value-matching and smooth-pasting conditions which link the value function and the option function at $\Pi^{*'}$. Since the left-hand branch gives the solution more easily we concentrate on it[16].

First, let us compute the solutions of the option functions, and then turn to the value functions. The solutions of the above equations are found by starting

[15] For further details on the mathematical steps, see Dixit and Pindyck (1994, pp. 200-207).

[16] This is the same procedure followed by Dixit and Pindyck (1994, pp. 202-204).

with the post-reform case (where policy uncertainty has vanished) and, then, going backward to the uncertain pre-reform case.

Expanding the RHS of [V.2] and using Itô's Lemma we obtain

$$O_1(\Pi) = (1 - rdt)\left[O_1(\Pi) + (r-\delta)\Pi O_{1_\Pi} dt + \frac{\sigma^2}{2}\Pi^2 O_{1_{\Pi\Pi}}\right] dt + o(dt)$$

Simplifying and dividing by dt and eliminating all the terms multiplied by $(dt)^2$ we have

$$[V.5] \quad rO_1(\Pi) = (r-\delta)\Pi O_{1_\Pi} + \frac{\sigma^2}{2}\Pi^2 O_{1_{\Pi\Pi}}$$

The solution of $O_1(\Pi)$ has the standard form $O_1(\Pi) = G\Pi^{\beta_1}$where G is unknown.

Turn next to the uncertain pre-reform option function $O_0(\Pi)$. Expanding the RHS of [V.1] and using Itô's Lemma we obtain

$$\begin{aligned} O_0(\Pi) &= (1 - rdt)\left\{O_0(\Pi) + ((r-\delta)\Pi O_{0_\Pi} + \frac{\sigma^2}{2}\Pi^2 O_{0_{\Pi\Pi}})\right\} + \\ &\quad + \lambda_2 dt\left[O_1(\Pi) - O_0(\Pi)\right] + o(dt) \end{aligned}$$

which simplifies as follows

$$[V.6] \quad (r+\lambda_2)O_0(\Pi) = (r-\delta)\Pi O_{0_\Pi} + \frac{\sigma^2}{2}\Pi^2 O_{0_{\Pi\Pi}} + \lambda_2 O_1(\Pi)$$

Now, let us define $O_s = O_0 - O_1$ as the effect of policy uncertainty on the option value. Subtracting equation [V.5] from [V.6] one obtains

$$[V.7] \ (r+\lambda_2) = O_s = (r-\delta)\Pi O_{s_\Pi} + \frac{\sigma^2}{2}\Pi^2 O_{s_{\Pi\Pi}}$$

which has the following solution

$$O_s(\Pi) = G_s \Pi^{\beta_1(\lambda_2)},$$

where $\beta_1(\lambda_2) > 1$ is the positive root of the characteristic equation

$$\frac{\sigma^2}{2}\beta(\beta-1) + (r-\delta)\beta - (r+\lambda_2) = 0$$

and G_s is unknown[17]. Now we can compute $O_0(\Pi)$

$$O_0(\Pi) = O_s(\Pi) + O_1(\Pi) = G_s\Pi^{\beta_1(\lambda_2)} + G\Pi^{\beta_1}.$$

[17]Note that $\beta_1(\lambda_2) > \beta_1 > 1$.

Let us now turn to the value function. Using the dynamic programming approach and expanding the RHS of [V.4] we obtain

$$V_1(\Pi) \;=\; \left\{\Pi - (r+\lambda_1)V_1(\Pi) + ((r-\delta)\Pi V_{1_\Pi} + \frac{\sigma^2}{2}\Pi^2 V_{1_{\Pi\Pi}})\right\} dt + V_1(\Pi) + \\ +\lambda_1 O_1(\Pi)dt + o(dt)$$

Defining $X_z = V_1 - O_1$, and using equations [V.4] and [V.5], one obtains

$$[V.8] \;\; (r+\lambda_1)X_z = \Pi + (r-\delta)\Pi Z_{z_\Pi} + \frac{\sigma^2}{2}\Pi^2 X_{z_{\Pi\Pi}}$$

which has the following solution

$$X_z(\Pi) = \frac{\Pi}{\lambda_1+\delta} + G_z \Pi^{\beta_1(\lambda_1)}$$

where $\beta_1(\lambda_1) > 1$ is the positive root of the characteristic equation

$$\frac{\sigma^2}{2}\beta(\beta-1) + (r-\delta)\beta - (r+\lambda_1) = 0$$

and G_z is unknown[18].

Turn now to the uncertain pre-reform case. Using the dynamic programming and applying Itô's Lemma to [V.3] we obtain

$$[V.9] \quad (r+\lambda_1+\lambda_2)V_0(\Pi) = \Pi + (r-\delta)\Pi V_{0_\Pi} + \frac{\sigma^2}{2}\Pi^2 V_{0_{\Pi\Pi}} + \lambda_2 V_1(\Pi) + \lambda_1 O_0(\Pi).$$

Finally, define $X_T = (V_0 - V_1) - (O_0 - O_1)$. Using function X_T and equations $[V.6]$, $[V.7]$, $[V.9]$ it is straightforward to obtain

$$[V.10] \quad (r+\lambda_1+\lambda_2)X_T(\Pi) = \Pi + (r-\delta)\Pi X_{T_\Pi}(\Pi) + \frac{\sigma^2}{2}\Pi^2 X_{T_{\Pi\Pi}}(\Pi)$$

which has the following solution

$$X_T = G_T \Pi^{\beta_1(\lambda_1+\lambda_2)}$$

where $\beta_1(\lambda_1+\lambda_2) > 1$ is the positive root of the characteristic equation

$$\frac{\sigma^2}{2}\beta(\beta-1) + (r-\delta)\beta - (r+\lambda_1+\lambda_2) = 0$$

[18] Note that $\beta_1(\lambda_1) > \beta_1 > 1$ and that $[\beta_1(\lambda_1) - \beta_1(\lambda_2)] \propto (\lambda_1 - \lambda_2)$.

and where G_T is unknown[19].

Using again equations [V.6], [V.7], [V.8] and [V.9] we obtain

$$V_0(\Pi) = X_T + V_1 + O_s = G_T \Pi^{\beta_1(\lambda_1+\lambda_2)} + (\frac{\Pi}{\delta+\lambda_1} + G_z \Pi^{\beta_1(\lambda_1)} + G\Pi^{\beta_1}) + G_s \Pi^{\beta_1(\lambda_2)}.$$

To sum up, in the region $\Pi \in [0, r_E I]$ we have four functions

$$V_0(\Pi) = \frac{\Pi}{\delta+\lambda_1} + G\Pi^{\beta_1} + G_z \Pi^{\beta_1(\lambda_1)} + G_s \Pi^{\beta_1(\lambda_2)} + G_T \Pi^{\beta_1(\lambda_1+\lambda_2)}$$

$$V_1(\Pi) = \frac{\Pi}{\delta+\lambda_1} + G\Pi^{\beta_1} + G_z \Pi^{\beta_1(\lambda_1)}$$

and

$$\begin{aligned} O_0 &= G\Pi^{\beta_1} + G_s \Pi^{\beta_1(\lambda_2)} \\ O_1 &= G\Pi^{\beta_1} \end{aligned}$$

where G, G_s, G_z and G_T are unknowns.

Let us now compute the trigger points under both policy certainty and policy uncertainty. Of course, the certain case is the same as that shown in Proposition 1, apart from depreciation. Using the VMC and SPC under certainty

$$[V_1(\Pi^{*'}) - I - O_1(\Pi^{*'})] = 0,$$

$$\frac{\partial}{\partial \Pi} \{(V_1(\Pi) - I - O_1(\Pi)\} |_{\Pi = \Pi^{*'}} = 0,$$

one obtains

$$\begin{aligned} \frac{\Pi}{\delta+\lambda_1} + G\Pi^{\beta_1} + G_z \Pi^{\beta_1(\lambda_1)} - I &= G\Pi^{\beta_1} \\ \frac{\Pi}{\delta+\lambda_1} + G\beta_1 \Pi^{\beta_1} + G_z \beta_1(\lambda_1) \Pi^{\beta_1(\lambda_1)} &= G\beta_1 \Pi^{\beta_1}. \end{aligned}$$

Solving the above two-equation system we obtain

$$\Pi^{*'} = \frac{\beta_1(\lambda_1)}{\beta_1(\lambda_1) - 1} \cdot (\delta + \lambda_1) I.$$

and

$$G_z = -\frac{1}{\beta_1(\lambda_1)} \cdot \frac{1}{\delta+\lambda_1} \cdot \Pi^{*' 1-\beta_1(\lambda_1)} < 0$$

[19] Note also that $\beta_1(\lambda_1+\lambda_2) > \beta(\lambda_i) \quad i = 1, 2.$

The computation of the critical value under policy uncertainty is trickier. Using the VMC and SPC under uncertainty

$$[V_0(\Pi) - I - O_0(\Pi)] = 0,$$

$$\frac{\partial}{\partial \Pi}\{(V_0(\Pi) - I - O_0(\Pi)\}|_{\Pi=\Pi^{*'}} = 0,$$

one obtains

$$[V.11]\ \frac{\Pi}{\delta+\lambda_1} + G\Pi^{\beta_1} + G_s\Pi^{\beta_1(\lambda_2)} + G_z\Pi^{\beta_1(\lambda_1)} + G_T\Pi^{\beta_1(\lambda_1+\lambda_2)} - I \;=\; G\Pi^{\beta_1} + G_s\Pi^{\beta_1(\lambda_2)}$$

$$[V.12]\ \frac{\Pi}{\delta+\lambda_1} + G_z\beta_1(\lambda)\Pi^{\beta_1(\lambda_1)} + G_T\beta_1(\lambda_1+\lambda_2)\Pi^{\beta_1(\lambda_1+\lambda_2)} \;=\; 0$$

Substituting equation [V.12] into [V.11] yields the following non-linear equation

$$[V.13]\quad \left[1 - \frac{1}{\beta_1(\lambda_1+\lambda_2)}\right]\frac{\Pi}{\delta+\lambda_1} + \left[1 - \frac{\beta_1(\lambda_1)}{\beta_1(\lambda_1+\lambda_2)}\right]G_z\Pi^{\beta_1(\lambda_1)} - I = 0.$$

Defining $x \equiv (\frac{\Pi}{\Pi^*})$and $\phi \equiv \left[\frac{\beta_1(\lambda_1+\lambda_2)-\beta_1(\lambda_1)}{\beta_1(\lambda_1)[\beta_1(\lambda_1+\lambda_2)-1]}\right]$, equation [V.13] can be rewritten as follows

$$x - 1 = \phi\left(x^{\beta_1(\lambda_1)} - 1\right).$$

As can be noted, solution $x = 1$ holds, namely $\Pi = \Pi^{*'} = \frac{\beta_1(\lambda_1)}{\beta_1(\lambda_1)-1}(\delta+\lambda_1)I$. Easy computations show that if $\Pi = \Pi^{*'}$ then $G_T = 0$. Compute now the other solutions (if any). If there exist other solutions Π^{**}, inequalities $\beta_1(\lambda_1) > 1$, and $\phi < 1$ are sufficient to obtain the inequality $\Pi^{**} > \Pi^{*'}$. In this case, it is easy to show that $G_T > 0$.

Let us now compute the solution which is optimal for a rational firm. As will be shown, the firm will choose the lower solution, that is ($\Pi = \Pi^{*'}$, $G_T = 0$). To show this, we must prove that the other solutions (if any) Π^{**} are sub-optimal. Rewrite equation [V.10] as

$$[V.10]\ X_T = (V_0 - O_0 - I) - (V_1 - O_1 - I) = G_T\Pi^{\beta_1(\lambda_1+\lambda_2)}.$$

and assume ab absurdo that Π^{**} is the optimal trigger point. If so, given the VMC and SPC, equalities $X_T(\Pi^{**}) = X_T^{'}(\Pi^{**}) = 0$ must hold. However, it is straightforward to see that inequality $X_T(\Pi^*) > 0$ holds. Namely, in the interval

$\Pi \in (0, \Pi^{**})$, there exists at least a point ($\Pi = \Pi^{*'}$) such that the value of the project, net of both the opportunity and the effective cost, is positive. If so, there is no reason for waiting until the payoff Π^{**} is reached. In economic terms, therefore, the solutions ($\Pi^{**} > \Pi^{*'}, G_T > 0$) (if any) are economically sub-optimal. The only acceptable solution is ($\Pi^{*'}, G_T = 0$). The proposition is thus proven. ■

As explained in Panteghini (2000b), if the imputation rate is high enough, the firm investing immediately will neither pay any tax (because of the tax holiday) nor it will benefit from any tax refund (because of the elimination of tax refundability). Like the firm deciding to postpone investment, therefore, only future taxation matters. As shown by Proposition 2, future taxes do not affect the investment timing, and thus time consistency is guaranteed.

6. A numerical example

Before concluding, we propose a numerical example based on long-term data. To give a feeling for the size of r_E in a real life setting we propose a numerical simulation. We use Goetzman and Jorion's (1999) estimates of the long-term average compound return μ of five stock markets - Denmark, Sweden, Switzerland, the UK and the USA - for the period 1921-95, with the exceptions of Denmark (1923-95) and Sweden (1926-95). We compute a numerical simulation based on a long-term macroeconomic dataset to show that the non-refundability system can discount the dramatic changes and fluctuations of history. To compute the minimum opportunity cost r_E^*, interest rates on riskless bonds are necessary. We employ Homer and Sylla's (1991) data on the long-term government bond rates of interest. These data cover the 1920-89 period, with the exception of Denmark (1930-89). For simplicity, we assume that capital does not depreciate.

Country	μ	δ	r_E^*	$r_E^* - \mu$	$r_E^* - r$	standard error
Denmark	4.88	4.24	9.41	4.53	1.51	1.51
Sweden	7.13	3.83	8.34	1.21	2.56	1.99
Switzerland	5.57	3.45	6.49	0.92	2.34	1.71
UK	8.16	5.17	8.98	0.82	2.70	1.75
USA	8.22	4.84	8.27	0.05	3.42	1.95

Table 1- A comparison of Stock Market performances and the minimum opportunity cost (in %). Sources: Goetzman and Jorion (1999) (for Stock Markets data) and Homer and Sylla (1991) (for r).

As shown in Table 1, at least three interesting results can be found. First, despite the relatively high stock volatility over this century (the standard deviation ranges from 12.88 in Denmark to 16.85 in the USA), the range of r_E^* is fairly narrow (6.49 for Switzerland to 9.41% for Denmark).

Second, the difference $r_E^* - \mu$ is low, except for Denmark. In this country, however, the stock market registered quite poor performances. In Sweden, Switzerland and the UK, the same difference is about one hundred basis points (121, 92 and 82 respectively). Finally, the USA show a difference of just 5 basis points: in terms of statistical significance this difference is null, and the neutral imputation rate is equal to the average rate of return.

The third result regards the difference $r_E^* - r$, which measures the ad hoc additional benefit able to neutralise the non-refundability asymmetry. Unlike the second result, the Danish parameter is not an outlier, as it requires only an additional relief of 151 basis points. In the USA, the differential $r_E^* - r$ is relatively higher. As we have seen, however, rate r_E^* is almost equal to the average rate of stock return and, thus, its value looks realistic.

The above results show that, on average, the decision to employ a non-refundability tax device can be implemented on the basis of realistic values of r_E^*. By realistic values we mean values reflecting the long-term (and, thus, statistically significant) performances of stock markets.

7. Conclusion

In this article, a non-refundability corporate tax system has been discussed. Though it is generally believed that an asymmetric design is distortive, this is not so if the imputation rate is adjusted so as to neutralise the effects of tax asymmetry. Since this rate is not affected by the statutory tax rate, the non-refundability system is neutral.

The system discussed is neutral from a dynamic point of view as well. We have shown that the effects of future uncertain taxation on both the project and option value neutralise each other. Under this regime, therefore, time consistency problems are not relevant and the government may benefit from a higher degree of freedom.

The model presented discusses an once-and-for-all decision. Though depreciation and the option to restart make it rather realistic, the further step of research will be the study of sequential and/or incremental investment. As pointed out by Dixit and Pindyck (1998), in fact, firms tend to expand their production gradually[20]. As shown by Dixit (1995), however, the investment decision depends on whether the returns to scale are increasing or decreasing. In the former case, investment is lumpy, in order to cross the region of increasing returns. The thresholds that trigger these jumps are such that 'the expected total return exceeds the Marshallian normal return by the same factor that captures the option value of waiting' [p. 328]. Thus, the model used in this paper implicitly studies an incremental case with increasing returns to scale. What remains to do is the study of the latter case, with decreasing returns to scale (see e.g. Bertola (1998)). This is a topic for further research.

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