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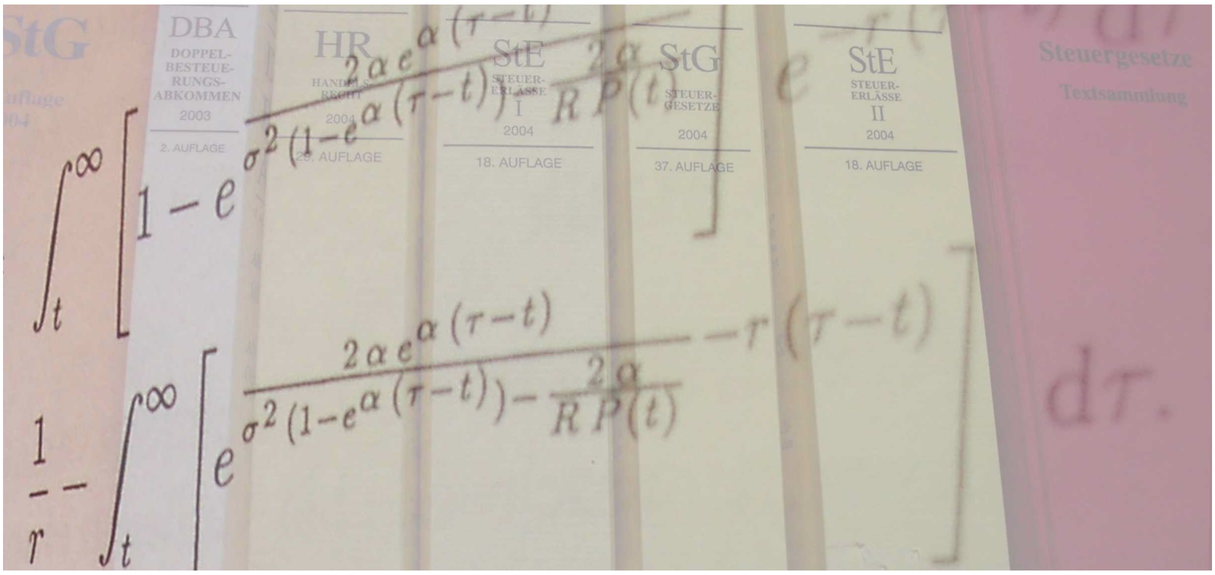

Diskussionsbeitrag Nr. 77
(zugleich Beitrag zur Festschrift für Franz W. Wagner zum 65. Geburtstag)

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Mai 2009

arqus Diskussionsbeiträge zur Quantitativen Steuerlehre
arqus Discussion Papers in Quantitative Tax Research
ISSN 1861-8944

Investment Effects of Capital Gains Taxation under Simultaneous Investment and Abandonment Flexibility

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Abstract

The influence of capital gains taxes on investment decisions is a central issue of accounting and public finance research. However, the implications of capital gains taxes on investors' willingness to invest in irreversible projects with entry and exit flexibility have not yet been a focal issue. As a result, the effects of taxing capital gains on the interdependencies of investment and divestment decisions have to be identified, especially under timing flexibility. This paper closes this gap by simultaneously analyzing investment timing and abandonment decisions for risky irreversible investment projects with uncertain cash flows under differential tax rates for ordinary income and capital gains. We investigate whether capital gains taxes affect immediate and delayed investment asymmetrically. Furthermore, we investigate the impact of capital gains taxation on the optimal abandonment decision. Performing extensive numerical simulations we find that varying the liquidation proceeds affects the decision whether or not to postpone the investment decision. Higher cash flow volatility favors delayed investment. We find that the introduction of capital gains taxation tends to be harmful for immediate investment. Moreover, we show that taxing capital gains may induce a tax paradox for delayed investment. Depending on the pre-tax parameter setting the future value of delayed investment may even increase in absolute terms for increasing capital gains tax rates. For sufficiently high liquidation proceeds capital gains taxation tends to favor continuation of a project. We find taxing capital gains mainly induces other, but not necessarily less arbitrary distortions than exempting capital gains.

1 Introduction

The taxation of capital gains is one of the key features of an income tax system.[1] Many jurisdictions, including the U.S., treat capital gains differently from ordinary income. Frequent adjustments of capital gains tax rates initiated many empirical studies concerning corporate investment and financing policy.[2] Other countries do not tax capital gains at all if some preconditions are met. For example, Greece, Latvia, Poland, Romania and Switzerland usually refrain from taxing capital gains from selling non-business property. E.g., according to the Danish, Dutch, Estonian, Bulgarian, Finnish, French, German, Hungarian, Spanish and Swedish tax law, gains and losses from the disposal of business property are taxable as ordinary income, whereas gains from selling non-business securities will be subject to a flat capital gains tax rate[3]. In Austria, the Czech Republic, Great Britain, Lithuania, Luxembourg, and Portugal, private capital gains are tax-exempt if the time spread between acquisition and disposal exceeds a specific period of time.[4] Even countries with tax systems close to theoretically ideal tax systems like the nordic Dual Income Tax have developed a variety of capital gains tax regimes.[5] Currently, the introduction of a tax on (non-speculative) private capital gains is still hotly debated in several countries, e.g. in Austria.

The heterogeneity of capital gains taxation is reflected by the political tax reform discussion, which is often characterized by a lack of economic arguments. This is true for the Austrian and the German debate prior to the introduction of the general capital gains tax. The influence of taxes on investment decisions has been a central issue of accounting and public finance research for many years. Several studies analyze whether and in what direction capital gains taxation distorts investment decisions. Although real-world investment decisions are typically characterized by irreversibility, neither the implications of capital gains taxes on investors' general willingness to invest nor on their willingness to invest in irreversible projects nor in projects with entry and exit flexibility have been a focal issue until now. In the light of irreversibility, flexibility with respect to investment and abandonment timing should be optimally used in order to avoid a waste of resources. Flexibility under irreversibility is analyzed in the real options literature.

[1] For a comprehensive overview see Zodrow (1993).

[2] See, e.g., Lang/Shackelford (2000); Shackelford/Verrechia (2002); Blouin/Raedy/Shackelford (2003); Ayers/Lefanowicz/Robinson (2003); Keuschnigg/Nielsen (2004). Further, see section 2.

[3] In Italy and the Netherlands capital gains from selling stocks are only subject to capital gains tax if the shareholder holds a substantial share in the corporation. In Denmark the capital gains tax rate depends on the capital gains tax base. In Germany a flat tax on dividends and capital gains will be effective beginning in 2009.

[4] This period varies between six months in Luxembourg and five years under specific conditions in the Czech Republik. In most countries there are special rules for real estate. Great Britain provides a limited, i.e. partial, tax-exemption of capital gains depending on the holding period.

[5] See, e.g., Nielsen/Sørensen (1997); Boadway (2004); Lindhe/Södersten/Öberg (2004); Sørensen (2005) and Kanniainen/Kari/Ylä-Liedenpohja (2007).

The impact of ordinary taxation on irreversible investment has been extensively analyzed. Although the effects of capital gains taxes on investment and abandonment timing are well-known to be important determinants of a project's profitability, the interdependencies of capital gains taxes, investment and divestment decisions have not yet been identified, especially under timing flexibility. This paper closes this gap by simultaneously analyzing investment timing and abandonment decisions for risky investment projects under differential tax rates for ordinary income and capital gains.

Our model addresses three major issues arising in the context of capital gains taxation. Firstly, the impact of introducing capital gains taxes on real compared to financial investment is a traditional research question in capital budgeting. Secondly, we analyze the effects of taxing capital gains on investment timing by introducing an option to invest in case of risky investment opportunities. This means that the investor has the opportunity to choose between immediate and delayed investment. We investigate whether capital gains taxes affect immediate and delayed investment asymmetrically. Thirdly, our model includes an option to abandon a risky project realized in the past. Thus, the investor chooses between liquidating and continuing a project. We analyze the impact of capital gains taxation on the optimal abandonment decision. Until now, there is no analytical model, which comprises the tax effects under simultaneous investment timing and abandonment flexibility.

The remainder of the article is organized as follows: After a brief review of the literature in section 2 we present the investment model in the pre-tax case and derive rules for optimal investment and abandonment decisions in section 3. Since the model leaves only limited room for analytical solutions, numerical examples in the pre-tax case are discussed extensively in section 4. In section 5, we introduce the tax system, including several different tax rates, and solve the resulting investment problem. We analyze the economic effects of introducing capital gains taxes numerically in section 6. Section 7 concludes.

2 Literature review

The influence of taxes on investment decisions has been analyzed by accounting researchers and public economics for many years. Several studies focused on the economic effects of individual and corporate income taxation, but neglected real-world characteristics of tax systems like capital gains taxation[6].

Under certainty a vast body of theoretical analyses shows that asymmetric taxation of current operating profits (or dividends) and capital gains may invoke severe distortions. E.g., *Holt/Shelton (1961)* analyze the impact of the capital gains tax on individual investment decisions. *Stiglitz (1969)* investigates the effects of capital gains taxes on the demand for risky assets. *Pye (1972)* shows that preferential capital gains taxation influences optimal dividend policy. *Balcer (1983)* integrates capital gains taxes and taxes on dividends and thereby derives a neutral tax rule. *Seastrand (1988)* investigates whether taxpayers respond to changes in state tax rates as well as federal tax rates when realizing capital gains. *Auerbach (1989, 1991)* discusses the distortions associated with capital gains taxes, and proposes a capital gains tax system that eliminates the incentive to defer the realization of capital gains which does not require unobservable knowledge. *Bradford (1996)* extends this work with respect to financial instruments. *Scholz (1988)* analyzes how changes in relative tax treatment of dividends and capital gains influence investor behavior and shows that the dividend clientele effect is significantly reasonable. *Klein (1999, 2001)* and *Viard (2000)* extend the framework with respect to uncertainty and demonstrate that the disincentive to sell an investment project increases with shareholders' capital gains tax exposure.

Haugen/Wichern (1973) investigate the effect of the capital gains tax on the stability of stock prices using a simulation. *Meade (1990)* analyzes the impact of capital gains taxes on private investment in an experimental study. *Auerbach (1992)* studies analytically and by simulation the distortive effects of capital gains tax reforms on investment decisions. *Dempsey (1998)* observes that high nominal levels of capital gains tax may work to increase the volatility of equity share ownership, destabilise share prices, and distort the viability of firms as on-going concerns. *Sureth/Langeleh (2007)* investigate the influence of different systems of corporate

[6] Neutral tax systems as a reference concept for analyzing tax effects have been proved under certainty by Brown (1948); Samuelson (1964) and Johansson (1969). Furthermore, cf. Hartman (1978); Boadway/Bruce (1984); Fane (1987) and Bond/Devereux (1995).
MacKie-Mason (1990) models nonlinear tax effects under uncertainty and demonstrates that policy may subsidize or discourage individual investment depending on the tax system. Under uncertainty, enriching the real option literature by integrating taxation (e.g., Harchaoui and Lasserre (1996); Jou (2000); Pennings (2000); Agliardi (2001); Panteghini (2001, 2004, 2005); Niemann/Sureth (2004, 2005); Gries/Prior/Sureth (2007), and Koskela/Alvarez (2008)) leads to investment rules that consider managerial flexibility, irreversibility and tax effects. Further, under specific assumptions it is possible to identify tax systems that are neutral with respect to investment decisions. For risk neutral investors, neutral tax systems have already been proved in the real option context by Niemann (1999) and Sureth (2002). First results for neutral taxation under risk aversion have been presented by Niemann/Sureth (2004).

income and capital gains taxation on investors' decisions to either carry out an investment in corporate shares or to invest funds on the capital market. Applying a growth model and performing a Monte Carlo Simulation they find that a full imputation system may cause more severe distortions than shareholder relief systems, and a dominating impact of capital gains taxation. *Ehling et al. (2008)* study the consumption-portfolio problem with capital gains taxation and its implications for trading strategies under limited loss offset.

Furthermore, empirical studies for different countries, industries, and tax reforms provide evidence on the effects of capital gains taxes on asset pricing and entrepreneurial decisions. E.g., *Cook/O'Hare (1992)* and *Liang/Matsunaga/ Morse (2002)* study the effects on the holding period of capital assets caused by change in the tax rate on capital gains. They find that the expected holding period is a significant variable in explaining the market reaction to a change in capital gains tax rate. *Burman/Clausing/O'Hare (1994)* and *Burman/Randolphs (1994)* investigate taxpayer behavior in response to transitory tax changes. They find evidence that responses to capital gains tax reform are dramatic and indicate that the elasticity of response of taxpayers to transitory variations in capital gains tax is greater than the response to permanent variations. In an event study, *Jang (1994)* revealed that, during legislative transition period in the U.S., high yield stocks generally earned positive abnormal returns and low yield stocks earned negative returns.

The capital gains lock-in effect is subject of an empirical study by *Landsman/Shackelford (1995)*. *Guenther/Willenborg (1999)* and *Downer (2001)* examine the impact of capital gains taxation on investment decisions of small and medium sized enterprises and find that a reduction in capital gains tax encourages investment. *Feldstein/Yitzhaki (1978)*, *Feldstein/Slemrod/Yitzhaki (1980)* present sets of econometric estimates of the effect of capital gains tax on the selling of common stock indicating that there is a substantial effect. *Gordon/Bradford (1980)* measure the relative valuation of dividends and capital gains in the stock market, using a variant of the capital asset pricing model.

Slemrod (1982) shows that the abnormal year-end behavior on the stock market is driven by tax reasons. *Seida/Wempe (2000)* examine individual investors' short- and long-term trading reaction to a capital gains tax rate increase. *Wu/Hsu (1996)*, *Reese (1998)*, *Lang/Shackelford (2000)*, *Shackelford (2000)* and *Akindayomi/ Warsame (2007)* empirically derive the extent to which stock prices react to cuts in the capital gains tax rate. *Shackelford/Verrecchia (2002)* and *Blouin/Raedy/ Shackelford (2003)* show that capital gains taxes induce investors to defer selling appreciated stock and may dampen trading volume and amplify price changes around the time of public disclosures. *Ayers/Lefanowicz/Robinson (2003)* test empirically whether capital gains taxes affect premiums paid on corporate acquisitions. Their evidence suggests that shareholder-level taxes have a significant price effect on acquisitions which varies with the tax status of the target's shareholder. *Keuschnigg/Nielsen (2004)* empirically analyze the influence of capital gains taxes on start-up finance with double moral hazard. *Edmiston (2004)* estimates tax volatility in a cross-country investigation and provides a panel regression suggesting that the volatility of effective tax rates on capital income has a significant negative impact on investment. Corresponding to the findings of *Poterba (1989a, 1989b)*, they point out that capital gains taxes particularly discourage entrepreneurial efforts. *Sinai/Gyourko (2004)* investigate the effect of a capital gains tax reduction on the share prices of real estate firms while *Dhaliwal/Erickson/Heitzman (2004)* do the same for acquisition prices. *Blouin/Hail/Yetman (2005)*, *Cook (2006)* and *Dai et al. (2006)* examine empirically the response of equity values to the announcement of a decrease in the capital gains tax rate.

The interdependencies of profit taxation and capital gains taxation may influence the timing and profitability of investment under divestment flexibility. These issues have not been simultaneously analyzed in literature yet. It is important to introduce these aspects into decision models under uncertainty to identify the impact of capital gains taxes on investor's willingness to invest.

3 Pre-tax model

Our model is a discrete-time model with a discrete state space. For simplicity, we assume a time horizon of $T = 3$ periods. This is the shortest possible time horizon that simultaneously permits to analyze an option to invest and an option to abandon.[7] The model is based on a purely individual calculus. At the starting time $t = 0$, the investor owns initial equity capital $I_0 = 1$, which corresponds to the acquisition costs of a project with stochastic cash flows. Cash flow uncertainty is modeled by a geometric binomial process. At any time t the project's cash flow denoted by π_t moves either upward or downward:

$$\pi_{t+1} = \begin{cases} (1+u)\ \ \pi_t & \text{with probability } p \\ (1+d)\ \ \pi_t & \text{with probability } 1-p \end{cases} \tag{1}$$
$$\text{with } u > d,\ \ t = 0,\ldots,\ T-1.$$

The publicly observable initial value is given by π_0. The upward probability p is the investor's subjective probability. The upward and downward movements u and d are also individual estimations by the investor. The investment project is regarded as an innovative combination of numerous single assets. The spanning property does not hold.[8] As a result, the completed project yields cash flows that cannot be

[7] Our model is in line with the Dixit/Pindyck (1994) model who use a continuous-time approach with an infinite time horizon. Since our objective is to identify the effects of capital gains taxation on investment and abandonment decisions, we need a discrete-time model with a finite time horizon.

[8] See e.g. Dixit/Pindyck (1994), pp. 147 ff., Trigeorgis (1996), p. 72 ff.

duplicated by traded assets. The project's resulting cash flows are not related to the sum of the acquisition costs or liquidation proceeds of the single assets. Therefore, the investor has to assess the entire project individually and cannot refer to market values.

The investor has an option to delay. This means that there is flexibility to invest either in period $t=0$ or in $t=1$. The date of investment is denoted by t_I. The earliest cash flows accrue one period after investment, i.e. π_I in $t=1$ or π_2 in $t=2$. The initial outlay necessary to acquire the investment project is constant and given by I_0. In principle, the acquisition costs could be modeled as deterministic or stochastic functions. For reasons of analytical simplicity, we focus on a constant I_0.[9] If the investor does not invest immediately in $t=0$ he does not receive the cash flow π_I. In this case, the equity capital yields the risk-free return r. Then, at time $t=1$ the investor faces the decision to invest again. If he decides to invest, he receives the remaining cash flows until the time horizon or the liquidation date is reached. Otherwise, his wealth is compounded at the exogenously-given interest rate r until $t = T$. Apart from π_0, the interest rate r is the only parameter, which is determined by the market.

If the investor decides to carry out the project in $t=0$ or $t=1$ he also obtains an option to abandon the project prematurely in $t=2$. Without exercising the option to abandon the investor would receive cash flows until the time horizon $t=T=3$. In contrast, if the option is exercised in $t=2$, the investor abandons the entire project and receives the liquidation proceeds L_2, but no cash flows π_3. L_2 is an individual estimation by the investor and is not endogenously derived in the model. The liquidation proceeds can be interpreted as a lower bound for the sum of the single liquidation proceeds of the assets the investment project is composed of. The liquidation date is denoted by t_L.

Summarizing, the investor faces different decisions at three points of time:

- $t=0$: Now-or-later decision to invest immediately or to postpone the decision until $t=1$
- $t=1$: Now-or-never decision to invest or to quit the market
- $t=2$: Now-or-later decision to continue the business or to abandon the project (only if the project was implemented in $t=0$ or in $t=1$)

Graphically, the decision tree is displayed in fig. 1. Here, decision nodes are represented by numbered rectangles (11, 21, 22, 31,..., 38). Event nodes, i.e. upward

[9] The investment rule for an I_0 following a geometric Brownian motion is very similar to the investment rule for constant acquisition costs. See Dixit/Pindyck (1994), pp. 207 ff.

and downward movements of the cash flow process, are symbolized by dots. The capital letter L indicates a liquidation decision by the investor.

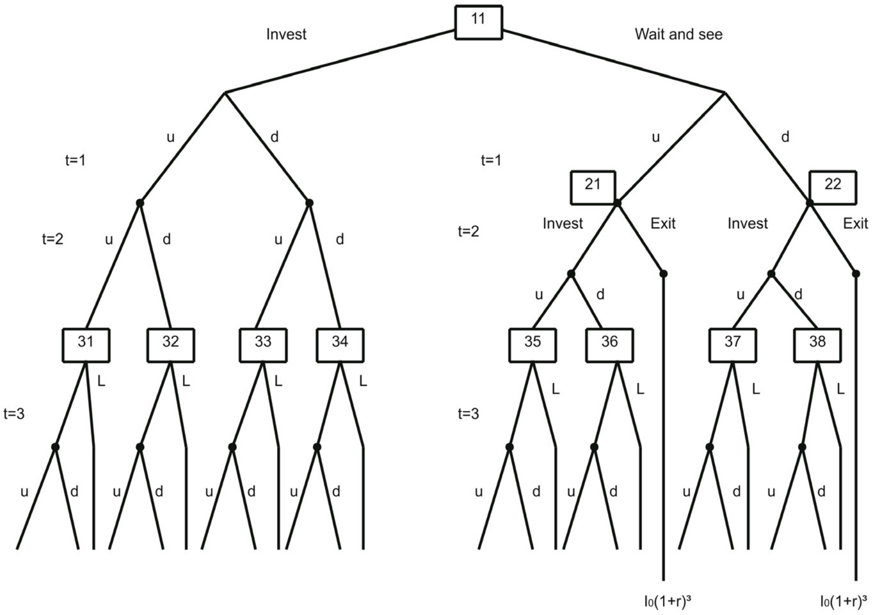

Fig. 1: Structure of decisions and events in the model.

The investor's objective variable is the future value at the time horizon T, denoted by FV_T. Although the investor can decide to abandon the project at time $t = 2$, a uniform time horizon is needed to compare the optimality of different decisions. We assume that the investor's consumption is financed by exogenous income from other sources. Hence, withdrawals are not necessary.

The investment/liquidation problem can be solved by backward induction, i.e. the decision to abandon (decision nodes 31-38 in fig. 1) has to be solved first. Each decision node corresponds to a particular combination of upward movements (u) and downward movements (d). If the project is in place, the investor observes the current cash flow π_2 that is characterized by three possible realizations[10]:

$$\begin{aligned}
\pi_2^{uu} &= (1+u)^2\, \pi_0 \\
\pi_2^{ud} &= \pi_2^{du} = (1+u)\ \ (1+d)\ \ \pi_0 \qquad (2)\\
\pi_2^{dd} &= (1+d)^2\, \pi_0.
\end{aligned}$$

For each of the possible realizations the optimal abandonment decision has to be reached. For the decision to abandon, decision nodes 31 and 35, both characterized by uu, require identical optimal decisions. The same holds for nodes 32 and 36

10 Superscripts ^{u} and ^{d} denote the current number of upward and downward movements of the cash flow process.

(ud), 33 and 37 (du), 34 and 38 (dd). This implies that the optimal liquidation decision does not depend on the time of investment in the pre-tax case.

We assume risk neutrality. The project will be liquidated in $t=2$ only if the compounded liquidation proceeds exceed the expected future value from the project's remaining cash flows[11]:

$$(1+r)\ L_2 > E_2\ [\pi_3] = \pi_2\big[p\ (1+u)+(1-p)\ (1+d)\big] = \pi_2\ q. \tag{3}$$

This means that liquidation is optimal if the liquidation proceeds divided by the current cash flow exceed the expected discounted value of the next cash flow movement:

$$\frac{L_2}{\pi_2} > \frac{p\ (1+u)+(1-p)\ (1+d)}{1+r} = \frac{q}{1+r}. \tag{4}$$

For ease of notation we use the abbreviation $q = p\ (1+u)+(1-p)\ (1+d)$. Obviously, higher liquidation proceeds L_2, lower current cash flows π_2, higher interest yield r, lower upward probability p, and lower upward movements u increase the likelihood of liquidation.

The remaining objective value at the decision nodes 31-38 is defined as the maximum of the compounded liquidation proceeds and the expected future cash flows from continuing the project[12]:

$$E_2^*\left[FV_T^{xx}\right] = \max\{(1+r)\ \ L_2;\ E_2\left[\pi_3\right]\} = \max\{(1+r)\ \ L_2;\ \pi_2\ \ q\},\ \ x \in \{u,\ d\}. \tag{5}$$

FV_T^{xx} describes the cash flows from current operations or liquidation proceeds in $t=3$ after upward or downward movements denoted by xx. Moving backwards, we arrive at time $t=1$ (decision nodes 21 (u) and 22 (d), respectively). Assuming that the investor has not invested in period $t=0$, he faces the decision between the deterministic future value from financial investment FV_T^{fin} and the uncertain future value of the project's remaining cash flows FV_T. The future value from financial investment as the default alternative is simply the initial wealth compounded at the interest rate r:

$$FV_T^{fin} = (1+r)^3\ I_0 = (1+r)^3. \tag{6}$$

---

11 Subscripts $_t$ in the expectations operator $E_t\left[\cdot\right]$ indicate the time of taking the expectation.

12 Superscripts * indicate optimal decisions.

The investor realizes the project at date $t=1$ if its expected future value exceeds the future value of financial investment: $E_1\left[FV_T\right]_{tI=1} > FV_T^{fin}$. The value of the project is defined as the future value of the remaining cash flows, taking the option to abandon into account. Moreover, the compounded interest income from the first period has to be added:

$$E_1\left[FV_T\right]_{tI=1} = (1+r)\ \ E_1\left[\pi_2\right] + E_1\left[E_2^*\left[FV_T^{xx}\right]\right] + r(1+r)^2. \tag{7}$$

To reach a decision in $t=1$, the upward and the downward cases have to be distinguished. The current cash flow is either $\pi_1^u = (1+u)\ \ \pi_0$ or $\pi_1^d = (1+d)\ \ \pi_0$. In the upward case, the project value is given by:

$$\begin{aligned} E_1\left[FV_T^u\right]_{tI=1} &= p\left[(1+r)\ \ (1+u)^2\,\pi_0 + E_2^*\left[FV_T^{uu}\right]\right] \\ &\quad +(1-p)\ \ \left[(1+r)\ \ (1+u)\ \ (1+d)\ \ \pi_0 + E_2^*\left[FV_T^{ud}\right]\right] + r(1+r)^2 \\ &= (1+r)\ \ (1+u)\ \ \pi_0\ \ q + p\ \ \max\left\{(1+r)\ \ L;\ (1+u)^2\,\pi_0\ \ q\right\} \\ &\quad +(1-p)\ \ \max\left\{(1+r)\ \ L;\ (1+u)\ \ (1+d)\ \ \pi_0\ \ q\right\} + r(1+r)^2. \end{aligned} \tag{8}$$

In the downward case, the future value of investing is:

$$\begin{aligned} E_1\left[FV_T^d\right]_{tI=1} &= p\left[(1+r)\ \ (1+u)\ \ (1+d)\ \ \pi_0 + E_2^*\left[FV_T^{du}\right]\right] \\ &\quad +(1-p)\ \ \left[(1+r)\ \ (1+d)^2\,\pi_0 + E_2^*\left[FV_T^{dd}\right]\right] + r(1+r)^2 \\ &= (1+r)\ \ (1+d)\ \ \pi_0\ \ q + p\ \ \max\left\{(1+r)\ \ L;\ (1+u)\ \ (1+d)\ \ \pi_0\ \ q\right\} \\ &\quad +(1-p)\ \ \max\left\{(1+r)\ \ L;\ (1+d)^2\,\pi_0\ \ q\right\} + r(1+r)^2. \end{aligned} \tag{9}$$

As a crucial result, the optimal investment decision involves the anticipation of the optimal abandonment decision.

The remaining objective value at the decision nodes in $t=1$, 21 (u) and 22 (d), given the optimal investment decision, is defined as the maximum of the possible future values:

$$\begin{aligned} E_1^*\left[FV_T^u\right]_{tI=1} &= \max\left\{(1+r)^3,\ E_1\left[FV_T^u\right]_{tI=1}\right\} \\ E_1^*\left[FV_T^d\right]_{tI=1} &= \max\left\{(1+r)^3,\ E_1\left[FV_T^d\right]_{tI=1}\right\}. \end{aligned} \tag{10}$$

Moving further backwards to the initial decision node 11, the investor faces the decision whether or not to delay investment. From (10), it can be easily seen that the ex ante value of delayed investment is defined as:

$$E_0\left[FV_T\right]_{t_I=1} = p\ \ E_1^*\left[FV_T^u\right]_{t_I=1} + \left(1-p\right)\ \ E_1^*\left[FV_T^d\right]_{t_I=1}. \tag{11}$$

If the investor invests in $t=0$, there is no flexibility at time $t=1$. In this case, the expected future value is defined as the expected value of the compounded cash flows of periods $t=1,\ 2$ and the remaining value taking into account the value of the option to abandon:

$$\begin{aligned} E_0\left[FV_T\right]_{t_I=0} &= \left(1+r\right)^2 E_0\left[\pi_1\right] + \left(1+r\right)\ \ E_0\left[\pi_2\right] + E_0\left[E_2^*\left[FV_T\right]\right] \\ &= \left(1+r\right)^2 \pi_0\ \ q + \left(1+r\right)\ \ \pi_0\ \ q^2 \\ &\quad + p^2\ \ \max\{\left(1+r\right)\ \ L;\ \ \pi_0\left(1+u\right)^2\ \ q\} \\ &\quad + 2p\left(1-p\right)\ \ \max\{\left(1+r\right)\ \ L;\ \ \pi_0\left(1+u\right)\ \ \left(1+d\right)\ \ q\} \\ &\quad + \left(1-p\right)^2\ \ \max\{\left(1+r\right)\ \ L;\ \ \pi_0\left(1+d\right)^2\ \ q\}. \end{aligned} \tag{12}$$

This value of investing immediately is compared to the optimal expected future value if the investor decides to wait until $t=1$. The project is realized in $t=0$ if its expected future value exceeds the expected future value from delayed investment:

$$E_0\left[FV_T\right]_{t_I=0} > E_0\left[FV_T\right]_{t_I=1}. \tag{13}$$

As a result, the expected future value of the project taking into account optimal exercise of all options is defined as the maximum of both values:

$$E_0^*\left[FV_T\right] = \max\left\{E_0\left[FV_T\right]_{t_I=0};\ \ E_0\left[FV_T\right]_{t_I=1}\right\}. \tag{14}$$

Due to the numerous non-linearities arising from the maximum operations, the optimal investment and liquidation policy cannot be immediately observed from the derived set of expressions above. Thus, the following questions should be analyzed numerically:

- Does the level of liquidation proceeds L_2 affect investment timing?
- Does the cash flow volatility, represented by the difference $u-d$, affect investment and liquidation timing?
- To what extent does the interest rate r affect investment and liquidation policy?

In order to illustrate the economic setting we will firstly investigate these issues in the pre-tax case. In sections 5 and 6, we will integrate taxation.

4 Numerical examples in the pre-tax case

To illustrate the impact of the different parameters on the investment and abandonment decisions we start with a symmetric scenario described by $p = \frac{1}{2};\ u = -d$. In this case the expectation q simplifies to $q = 1$. The remaining parameters $L_2,\ r,\ \pi_0$ will be varied.

Fig. 2 illustrates the investor's timing problem. The independent variable is defined by the liquidation proceeds L_2. The figure consists of four different value functions determining the optimal investment behavior. The thick solid line represents the future value $E_0\left[FV_T\right]_{tI=0}$ of investing immediately. Obviously, it increases with increasing liquidation proceeds. The kinks of the value function indicate switches of the optimal liquidation policy depending on the liquidation proceeds. The future value of financial investment FV_T^{fin} is given by the thin dotted line. It does not depend on the liquidation proceeds L_2. The dashed lines indicate the future values of two differently defined types of delayed real investment. The thin dashed line displays the future value of real investment carried out definitely in $t = 1$, regardless of the cash flow's realization π_1. This function is defined as $p\ \ E_1\left[FV_T^u\right]_{tI=1} + (1-p)\ \ E_1\left[FV_T^d\right]_{tI=1}$. It does not reflect the investor's flexibility to refrain from real investment by opting for financial investment in $t = 1$. However, it could be used to analyze tax effects on delayed real investment rather than a mixture of real and financial investment. The thick dashed line represents the value function $E_0\left[FV_T\right]_{tI=1} = p\ \ E_1^*\left[FV_T^u\right]_{tI=1} + (1-p)\ \ E_1^*\left[FV_T^d\right]_{tI=1}$. This function is the actual value function of delayed investment as defined in (11), taking into account the opportunity to choose between real and financial investment at time $t = 1$ after having observed π_1. For $E_0\left[FV_T\right]_{tI=1}$ the following relations hold:

$$
\begin{aligned}
&E_0\left[FV_T\right]_{tI=1} \geq \max\left\{FV_T^{fin},\ p\ \ E_1\left[FV_T^u\right]_{tI=1} + (1-p)\ \ E_1\left[FV_T^d\right]_{tI=1}\right\}\ \ \forall\ L_2 \\
\exists\ L_2 \,|\ \ &E_0\left[FV_T\right]_{tI=1} > \max\left\{FV_T^{fin},\ p\ \ E_1\left[FV_T^u\right]_{tI=1} + (1-p)\ \ E_1\left[FV_T^d\right]_{tI=1}\right\}.
\end{aligned} \tag{15}
$$

Fig. 2 is based on the parameter setting $r = 0.1,\ u = -d = 0.2,\ \pi_0 = 0.375$:

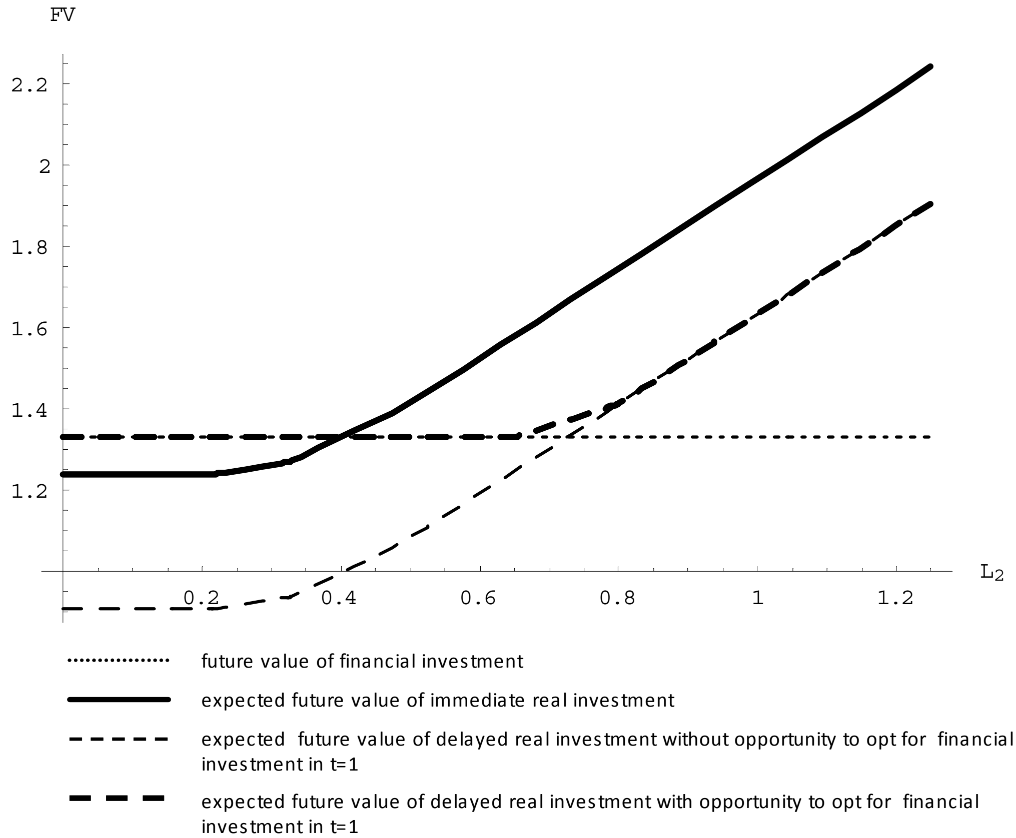

Fig. 2: Future values FV_T^{fin}, $E_0\left[FV_T\right]_{tI=0}$, $E_0\left[FV_T\right]_{tI=1}$ as functions of the liquidation proceeds L_2.

For ease of presentation and to focus on the decision aspects of capital gains taxation, for delayed investment only the value function $E_0\left[FV_T\right]_{tI=1}$, i.e., a scenario considering the opportunity to switch from the real to a financial investment in $t=1$, is displayed in the following figures.

The parameter setting $u=-d=0.2;\ \pi_0=0.2$ yields the following future values for financial investment FV_T^{fin} (thin dotted line), for immediate investment $E_0\left[FV_T\right]_{tI=0}$ (solid line), and for delayed investment $E_0\left[FV_T\right]_{tI=1}$ (dashed line), depending on the liquidation proceeds $L_2 \in [0,\ 1.5]$. The interest rates are $r=0.1$ (left graph) and $r=0.3$, respectively (right graph).

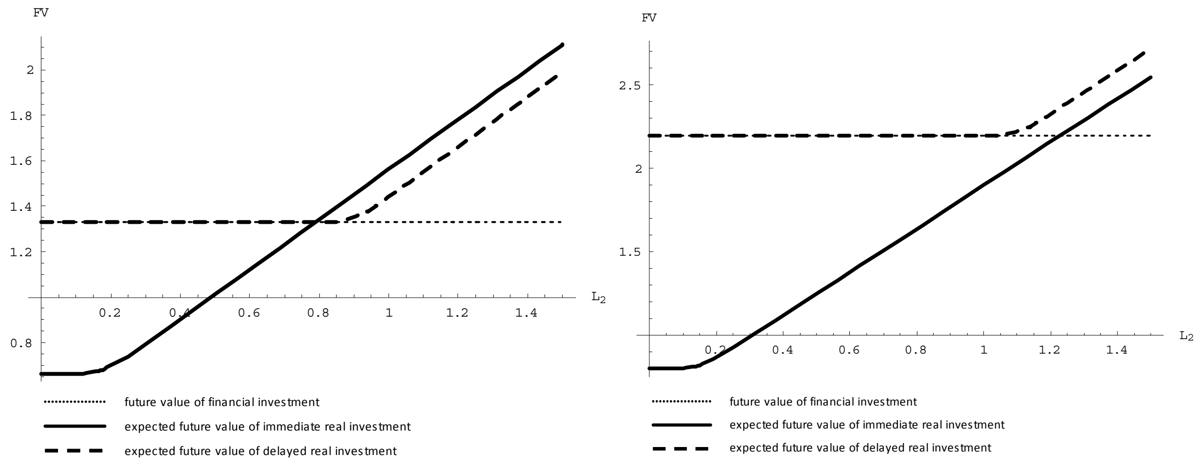

Fig. 3: Future values FV_T^{fin}, $E_0\left[FV_T\right]_{tI=0}$, $E_0\left[FV_T\right]_{tI=1}$ as functions of the liquidation proceeds L_2.

Obviously, it depends on the parameter setting whether immediate (left graph) or delayed investment is optimal (right graph). The level of liquidation proceeds L_2 affects optimal investment policy, as can be observed from the intersections of $E_0\left[FV_T\right]_{tI=0} / FV_T^{fin}$, and $E_0\left[FV_T\right]_{tI=1} / FV_T^{fin}$, respectively. For low values of L_2 financial investment is optimal. Here, real investment is non-optimal for $t_I = 0$ as well as for $t_I = 1$. For sufficiently high levels of L_2 ($L_2 > 0.79$ in the left graph), immediate investment is optimal. Delayed investment ($t_I = 1$) never maximizes the investor's future value for $r = 0.1$. Whereas for $r = 0.3$, delayed real investment dominates immediate investment for all values of L_2 and financial investment for $L_2 > 1.06$.

The future value of immediate investment is a piecewise linear function of the liquidation proceeds L_2. The kinks of the graphs indicate the critical values of L_2 for which the optimal liquidation policy changes. As can be seen from (4), the number of critical values ($= 3$) corresponds to the number of different states at the possible liquidation date $t = 2$. Given that the real investment project is in place, the optimal liquidation policy does not depend on investment timing. Thus, the critical values are identical for immediate and delayed investment in the pre-tax case as shown in equation (4).

Investment timing is substantially affected by variations of the interest rate r as can be seen from the following figure, which depicts the future values of financial investment FV_T^{fin} (dotted line), immediate real investment $E_0\left[FV_T\right]_{tI=0}$ (solid line), and delayed investment $E_0\left[FV_T\right]_{tI=1}$ (dashed line) as functions of the liquidation proceeds L_2. The parameters are $L_2 = 1.25,\ u = -d = 0.2,\ \pi_0 = 0.375$.

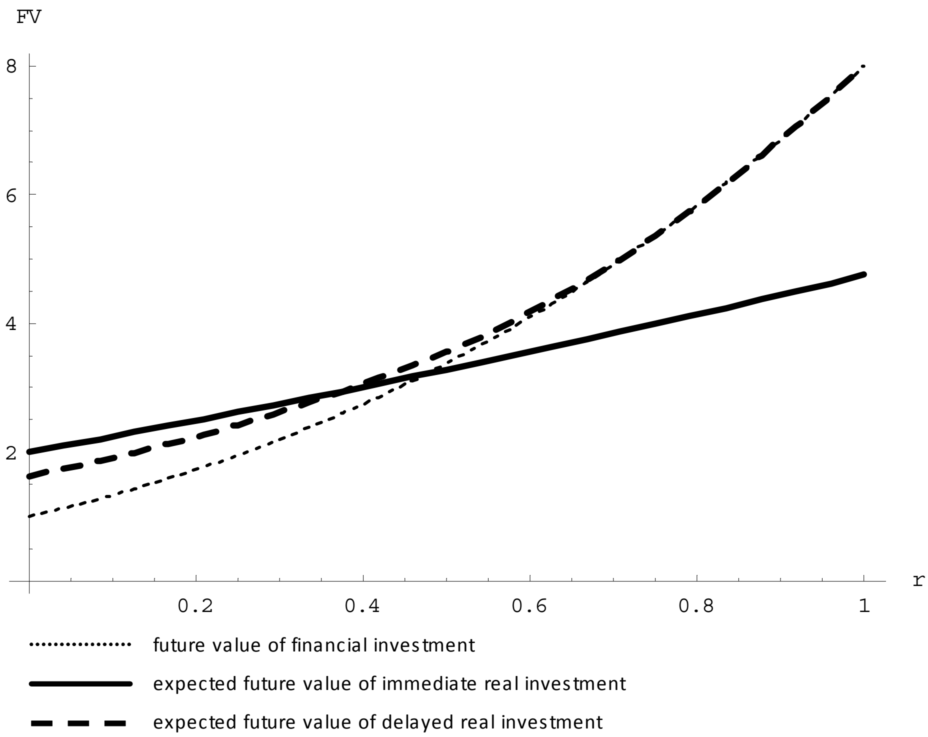

Fig. 4: Future values FV_T^{fin}, $E_0\left[FV_T\right]_{t_I=0}$, $E_0\left[FV_T\right]_{t_I=1}$ as functions of the pre-tax interest rate r.

Consistent with traditional investment theory, real investment is most attractive for low interest rates. As delayed investment contains a substantial interest income component, waiting becomes more attractive for higher interest rates. For very high interest rates, financial investment is optimal. Fig. 4 reveals that each investment alternative may be optimal for a particular interval of interest rates. However, there exist combinations of parameters, which induce that either immediate or delayed investment may be inferior for all possible interest rates.

Evidently, immediate investment becomes more attractive compared to delayed investment for higher values of the initial cash flow π_0. Since financial investment is unaffected by π_0 and there is a point of indifference between immediate and delayed investment, financial investment is optimal for very low values of π_0. Assuming sufficiently high liquidation proceeds L_2, delayed investment is optimal for intermediate starting values π_0, immediate investment is optimal for high levels of the initial cash flow. These relations can be observed from the following figure assuming the parameters $r = 0.1$, $L_2 = 1.5$ (left graph), and $L_2 = 0.5$ (right graph):

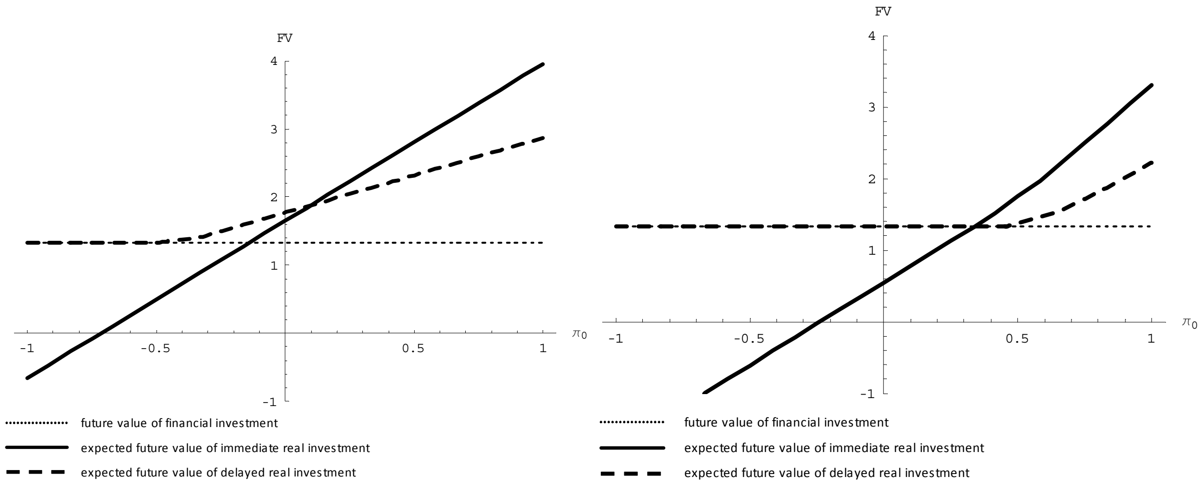

Fig. 5: Future values FV_T^{fin}, $E_0\left[FV_T\right]_{t_I=0}$, $E_0\left[FV_T\right]_{t_I=1}$ as functions of the initial observable cash flow π_0.

Fig. 5 illustrates that if L_2 does not reach a critical value, delayed investment may never be optimal, regardless of π_0 (right graph). Very high liquidation proceeds may even compensate for negative operating cash flows.

As in the preceding figures, dotted lines represent the future value of financial investment FV_T^{fin}, solid lines the future value of immediate investment $E_0\left[FV_T\right]_{t_I=0}$, and dashed lines the future value of delayed investment $E_0\left[FV_T\right]_{t_I=1}$.

Varying the volatility of cash flows reveals that the future values of real investment are convex with respect to the difference $u-d$. Fig. 6 shows that for symmetric upward and downward movements ($u=-d$) the future values are increasing in u. The underlying set of parameters is $L_2=0.7,\ \pi_0=0.375$. The interest rates are $r=0.1$ (left graph) and $r=0.2$ (right graph), respectively. This finding is consistent with traditional option pricing theory that says that option prices increase with increasing volatility of the underlying asset. In the setting considered here, real investment includes the option to abandon, which is more valuable for higher differences of u and d. Equation (5) gives the remaining future value at the decision nodes 31-38: $E_2^*\left[FV_T^{xx}\right]=\max\{(1+r)\ L_2;\ \pi_2\ q\}$. The term $(1+r)\ L_2$ is a lower bound, which is identical for each decision node. Since $\pi_2\in\left\{(1+u)^2\,\pi_0,\ \left(1-u^2\right)\ \pi_0,\ (1-u)^2\,\pi_0\right\}$, quadratic terms enter the value functions. In the expected value, these terms do not cancel out, because the maximum is computed separately at each decision node before the expectation is taken. According to equations (8), (9), (10), and (11), the computation of the future value of delayed investment $E_0\left[FV_T\right]_{t_I=1}$ involves a nested maximum operation, which tends to increase the coefficient of u^2 in the value function compared to immediate investment. Hence, the slope of $E_0\left[FV_T\right]_{tI=1}$ exceeds the slope of $E_0\left[FV_T\right]_{tI=0}$ for sufficiently high values of u. This effect favors delayed investment as can be inferred from the right part of fig. 6.

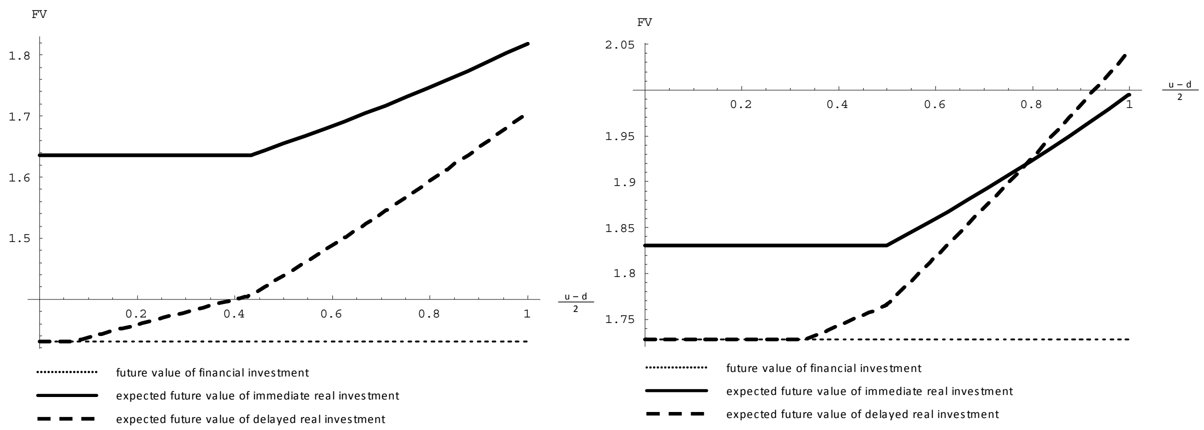

Fig. 6: Future values FV_T^{fin}, $E_0\left[FV_T\right]_{tI=0}$, $E_0\left[FV_T\right]_{tI=1}$ **as functions of the upward movement** $(u-d)/2$.

For asymmetric upward and downward movements ($u \neq -d$) the future values are not necessarily increasing in u.

Summarizing, the interrelation of the economic variables in the pre-tax case is quite straightforward. The following sections discuss whether this property is maintained after the integration of taxes or whether taxation – particularly capital gains taxation – induces severe distortions of investment timing and liquidation decisions.

5 Integrating Taxation

To isolate the impact of a capital gains tax, we assume that capital gains are subject to the tax rate τ^g, which may differ from the tax rate on ordinary (operating) income τ^o. Moreover, interest income is taxed at the rate τ^i. For simplicity, all tax rates are assumed proportional. We neglect loss-offset limitations, which would further complicate the analysis. If a tax base is negative, the taxpayer receives a tax reimbursement of $(\text{tax rate} \cdot \text{tax base})$.

The tax base for ordinary income b_t^o is defined as the difference of cash flows π_t and linear depreciation allowances[13] δ_t:

[13] For simplicity, we do not take other depreciation schedules like declining balance depreciation into account.

$$b_t^o = \pi_t - \delta_t = \pi_t - \frac{1}{T}. \tag{16}$$

Formally, the depreciation allowances are defined as:

$$\delta_1 = \begin{cases} \frac{1}{T} & if\, t_I = 0 \\ 0 & \text{otherwise} \end{cases}$$
$$\delta_2 = \begin{cases} \frac{1}{T} & if\, t_I \in \{0;\ 1\} \\ 0 & \text{otherwise} \end{cases} \tag{17}$$
$$\delta_3 = \begin{cases} \frac{1}{T} & if\, t_I \in \{0;\ 1\} \quad \wedge\ t_L = 3 \\ 0 & \text{otherwise} \end{cases}.$$

The tax base from (16) results in the after-tax cash flow π_t^τ:

$$\pi_t^\tau = \pi_t - \tau^o b_t^o = \left(1-\tau^o\right)\ \pi_t + \frac{\tau^o}{T}. \tag{18}$$

The project's useful life for tax purposes is given by $T = 3$. Since the time horizon is also defined as $T = 3$, a delayed project realized at time $t = 1$ still has a positive book value at time $t = T$. The same happens if a project acquired at $t = 0$ or $t = 1$ is abandoned in $t = 2$. The taxable capital gain b_t^g is the difference of liquidation proceeds and the project's book value:

$$b_2^g = L_2 - \left(1 - \sum_{s=1}^{t} \delta_s\right) \tag{19}$$

$$b_3^g = \begin{cases} 0 & if\, t_I = 0 \\ \delta_3 & if\, t_I = 1 \end{cases}. \tag{20}$$

This implies that the project's book value, the depreciation deductions, and a possible capital gain are path-dependent and contingent on the time of investment. In contrast to the pre-tax case, the decision nodes 31 and 35 (uu) (and 32/36 (ud), 33/37 (du), 34/38 (dd), respectively) do not necessarily induce identical optimal liquidation decisions.

In line with the pre-tax case the investment-liquidation problem has to be solved using backward induction. Since the taxation of ordinary income and capital gains may differ, the investor distinguishes between the different possible dates of investment. If the project was realized in $t_I = 0$, the book value BV_2 at time $t = 2$ is given by

$$BV_2\Big|_{tI=0} = I_0 - \delta_1 - \delta_2 = \frac{1}{3}. \tag{21}$$

In case of liquidation, the resulting capital gain or capital loss

$$b_t^g\Big|_{tI=0} = L_2 - BV_2\Big|_{tI=0} = L_2 - \frac{1}{3} \tag{22}$$

is taxed at the capital gains tax rate τ^g. The resulting net-of-tax liquidation proceeds L_2^τ are given by:

$$L_2^\tau\Big|_{tI=0} = L_2 - \tau^g\, b_t^g\Big|_{tI=0} = L_2 - \tau^g\left(L_2 - \frac{1}{3}\right) = \left(1-\tau^g\right)\; L_2 + \frac{\tau^g}{3}. \tag{23}$$

If the investor decides to continue the project, a capital gain or loss does not occur at date $t = T = 3$, because the project's remaining value and its book value are both equal to zero. The expected future value after taxes at date $t = 2$ can be computed taking the stochastic process as exogenous:

$$\begin{aligned} E_2\left[FV_T^\tau\right]_{tI=0} &= p\Big[(1+u)\;\; \pi_2\left(1-\tau^o\right) + \tau^o\delta_3\Big] + (1-p)\;\; \Big[(1+d)\;\; \pi_2\left(1-\tau^o\right) + \tau^o\delta_3\Big] \\ &= \left(1-\tau^o\right)\;\; \pi_2\left[p(1+u) + (1-p)\;\; (1+d)\right] + \tau^o\delta_3 \\ &= \left(1-\tau^o\right)\;\; \pi_2 q + \frac{\tau^o}{3}. \end{aligned} \tag{24}$$

The investor abandons the project if the after-tax liquidation proceeds, compounded at the after-tax interest rate $r^\tau = \left(1-\tau^i\right)\; r$, exceed the expected after-tax future value from operating the project:

$$\begin{aligned} \left(1+r^\tau\right)\;\; L_2^\tau\Big|_{tI=0} = \left[1+\left(1-\tau^i\right)\;\; r\right]\;\; \left[\left(1-\tau^g\right)\;\; L_2 + \frac{\tau^g}{3}\right] > E_2\left[\pi_3^\tau\right] = \left(1-\tau^o\right)\;\; \pi_2 q + \frac{\tau^o}{3} \\ \left(1+r^\tau\right)\;\; \left(1-\tau^g\right)\;\; L_2 - \left(1-\tau^o\right)\;\; \pi_2 q > \delta_3\left[\tau^o - \left(1+r^\tau\right)\;\; \tau^g\right]. \end{aligned} \tag{25}$$

Obviously, the condition for optimal abandonment is not as simple as in the pre-tax case (4). However, (25) permits to derive a critical capital gains tax rate at which the investor is indifferent between continuation and abandonment:

$$\begin{aligned} E_2\left[\pi_3^\tau\right] &= \left(1+r^\tau\right)\;\; L_2^\tau\Big|_{tI=0} \\ \tau^g &= \frac{\left(1-\tau^o\right)\;\; \pi_2 q + \frac{\tau^o}{3} - \left(1+r^\tau\right)\;\; L_2}{\left(1+r^\tau\right)\;\; \left(\frac{1}{3} - L_2\right)}. \end{aligned} \tag{26}$$

It should be noted that all three (possibly different) tax rates τ^i, τ^g, and τ^o as well as depreciation deductions δ_t appear in condition (25) and affect the decision to liquidate.

If the project was acquired in period $t=1$, it has been depreciated for only one period in $t=2$. Thus, the book value differs from (21) and amounts to $BV_2\big|_{t_I=1} = I_0 - \delta_2 = \frac{2}{3}$. The resulting capital gain $b_t^g\big|_{t_I=1} = L_2 - BV_2\big|_{t_I=1} = L_2 - \frac{2}{3}$ is taxed at the rate τ^g, so that the after-tax liquidation proceeds are given by:

$$L_2^\tau\Big|_{t_I=1} = L_2 - \tau^g\, b_t^g\Big|_{t_I=1} = L_2 - \tau^g\left(L_2 - \frac{2}{3}\right) = \left(1-\tau^g\right)\ L_2 + \frac{2}{3}\tau^g. \tag{27}$$

If the investor decides to operate the project until the time horizon T, it still has a positive book value $BV_3\big|_{t_I=1} = \frac{1}{3}$, because it was depreciated for only two periods. Assuming that the liquidation proceeds in $t=T=3$ equal zero, the investor realizes a capital loss that entitles to a tax reimbursement at the capital gains tax rate τ^g. Note that real-world tax systems may be characterized by different tax rates for sale and liquidation proceeds. This implies that taxpayers minimize their tax burden by arranging facts determining the tax base. These tax planning strategies are reflected by the optimization calculus in our model[14]. Thus, the after-tax liquidation proceeds at the time horizon T are positive:

$$L_3^\tau\Big|_{t_I=1} = 0 + \tau^g\, b_3^g\Big|_{t_I=1} = \frac{1}{3}\tau^g. \tag{28}$$

This term has to be added to the operating cash flows in $t=3$ if the optimal liquidation decision is considered. Liquidation in $t=2$ is optimal if the compounded after-tax liquidation proceeds exceed the expected after-tax operating cash flows in $t=3$ and the tax reimbursement from the capital loss in $t = T$:

$$\begin{gathered}\left(1+r^\tau\right)\ L_2^\tau\Big|_{t_I=1} = \left(1+r^\tau\right)\ \left[\left(1-\tau^g\right)\ L_2 + \frac{2}{3}\tau^g\right] > E_2\left[FV_T^\tau\right] = \left(1-\tau^o\right)\ \pi_2 q + \frac{\tau^o}{3} + \frac{\tau^g}{3} \\ \left(1+r^\tau\right)\ \left(1-\tau^g\right)\ L_2 - \left(1-\tau^o\right)\ \pi_2 q > \frac{1}{3}\left[\tau^o - \left(1+2r^\tau\right)\ \tau^g\right].\end{gathered} \tag{29}$$

[14] Although sale and liquidation are very much related tax systems often provide different tax rates for these different ways to quit an investment. Integrating different tax rates in a decision model can extremely complicate the calculus. See, e.g., Hundsdoerfer/Kruschwitz/Lorenz (2008) who show how the investment decision and the finance decisions can be optimized simultaneously. Based on simple premises they evaluate an indivisible investment project that is carried out in a corporation and find the decision problem turns out to be rather complex if different tax rates have to be considered.

The optimal liquidation decision depends on all tax rates τ^i, τ^g, and τ^o, the interest rate r, as well as the date of investment t_I. The critical capital gains tax rate at which the investor is indifferent between continuation and abandonment is given by:

$$E_2\left[FV_T^\tau\right]=\left(1+r^\tau\right)\ L_2^\tau\Big|_{tI=1}$$
$$\tau^g=\frac{\left(1-\tau^o\right)\ \pi_2 q+\frac{\tau^o}{3}-\left(1+r^\tau\right)\ L_2}{\left(1+r^\tau\right)\ \left(\frac{1}{3}-L_2\right)+\frac{1}{3}r^\tau}. \tag{30}$$

This critical capital gains tax rate falls short of the critical tax rate for immediate investment, as can be seen from (26). Consequently, continuation is more likely for delayed investment than for immediate investment.

The investor's remaining objective value at the decision nodes 31-34 (immediate investment) is defined as the maximum of the compounded after-tax liquidation proceeds and the expected future value from continuing the project:

$$\begin{aligned}E_2^*\left[FV_T^\tau\right]_{tI=0}&=\max\left\{\left(1+r^\tau\right)\ L_2^\tau;\ E_2\left[FV_T^\tau\right]_{tI=0}\right\}\\&=\max\left\{\left(1+r^\tau\right)\ \left[\left(1-\tau^g\right)\ L_2+\frac{\tau^g}{3}\right];\ \left(1-\tau^o\right)\ \pi_2 q+\frac{\tau^o}{3}\right\}.\end{aligned} \tag{31}$$

For delayed investment (decision nodes 35-38), the remaining objective value is given by:

$$E_2^*\left[FV_T^\tau\right]_{tI=1}=\max\left\{\left(1+r^\tau\right)\ \left[\left(1-\tau^g\right)\ L_2+\frac{2}{3}\tau^g\right];\ \left(1-\tau^o\right)\ \pi_2 q+\frac{\tau^o}{3}+\frac{\tau^g}{3}\right\}. \tag{32}$$

For positive tax rates, $E_2^*\left[FV_T^\tau\right]_{tI=1}>E_2^*\left[FV_T^\tau\right]_{tI=0}$. Hence, this tax system tends to delay investment.

Moving backwards to time $t=1$, we arrive at decision nodes 21 (u) and 22 (d), respectively. The future value from financial investment $FV_T^{fin,\tau}$ is simply the initial wealth compounded at the after-tax interest rate r^τ:

$$FV_T^{fin,\tau}=\left(1+r^\tau\right)^3 I_0=\left[1+r\left(1-\tau^i\right)\right]^3. \tag{33}$$

This value is compared to the expected future value of investing in $t=1$, which consists of the compounded expected after-tax cash flow from period $t=2$, the operating cash flow from period $t=3$, taking into account the option to abandon, and the compounded interest income from period $t=1$:

$$E_1\left[FV_T^{\tau}\right]_{tI=1}=\left(1+r^{\tau}\right)\ E_1\left[\pi_2^{\tau}\right]+E_1\left[E_2^{*}\left[FV_T^{\tau}\right]_{tI=1}\right]+r^{\tau}\left(1+r^{\tau}\right)^2. \tag{34}$$

The investor acquires the project in period $t=1$ if its expected future value exceeds the future value of financial investment:

$$E_1\left[FV_T^{\tau}\right]_{tI=1}>FV_T^{fin,\,\tau}. \tag{35}$$

Again, the upward state ($\pi_1=\left(1+u\right)\ \pi_0$) and the downward state ($\pi_1=\left(1+d\right)\ \pi_0$) have to be distinguished. In the upward state, the investor can reach the following expected future value after taxes from investing:

$$\begin{aligned}E_1\left[FV_T^{u,\,\tau}\right]_{tI=1}=&\ p\ \left(1+r^{\tau}\right)\ \left[\left(1-\tau^{o}\right)\ \left(1+u\right)^2\pi_0+\tau^{o}\delta_2\right]\\&+p\ \max\left\{\begin{matrix}\left(1+r^{\tau}\right)\ \left[\left(1-\tau^{g}\right)\ L_2+\frac{2}{3}\tau^{g}\right];\\ \left(1-\tau^{o}\right)\ \left(1+u\right)^2\pi_0 q+\frac{\tau^{o}}{3}+\frac{\tau^{g}}{3}\end{matrix}\right\}\\&+\left(1-p\right)\ \left(1+r^{\tau}\right)\ \left[\left(1-\tau^{o}\right)\ \left(1+u\right)\ \left(1+d\right)\ \pi_0+\tau^{o}\delta_2\right]\\&+\left(1-p\right)\ \max\left\{\begin{matrix}\left(1+r^{\tau}\right)\ \left[\left(1-\tau^{g}\right)\ L_2+\frac{2}{3}\tau^{g}\right];\\ \left(1-\tau^{o}\right)\ \left(1+u\right)\ \left(1+d\right)\ \pi_0 q+\frac{\tau^{o}}{3}+\frac{\tau^{g}}{3}\end{matrix}\right\}.\\&+r^{\tau}\left(1+r^{\tau}\right)^2.\end{aligned} \tag{36}$$

The corresponding expected future value after taxes in the downward state is given by:

$$\begin{aligned}E_1\left[FV_T^{d,\,\tau}\right]_{tI=1}=&\ p\ \left(1+r^{\tau}\right)\ \left[\left(1-\tau^{o}\right)\ \left(1+u\right)\ \left(1+d\right)\ \pi_0+\tau^{o}\delta_2\right]\\&+p\ \max\left\{\begin{matrix}\left(1+r^{\tau}\right)\ \left[\left(1-\tau^{g}\right)\ L_2+\frac{2}{3}\tau^{g}\right];\\ \left(1-\tau^{o}\right)\ \left(1+u\right)\ \left(1+d\right)\ \pi_0 q+\frac{\tau^{o}}{3}+\frac{\tau^{g}}{3}\end{matrix}\right\}\\&+\left(1-p\right)\ \left(1+r^{\tau}\right)\ \left[\left(1-\tau^{o}\right)\ \left(1+d\right)^2\pi_0+\tau^{o}\delta_2\right]\\&+\left(1-p\right)\ \max\left\{\begin{matrix}\left(1+r^{\tau}\right)\ \left[\left(1-\tau^{g}\right)\ L_2+\frac{2}{3}\tau^{g}\right];\\ \left(1-\tau^{o}\right)\ \left(1+d\right)^2\pi_0 q+\frac{\tau^{o}}{3}+\frac{\tau^{g}}{3}\end{matrix}\right\}\\&+r^{\tau}\left(1+r^{\tau}\right)^2.\end{aligned} \tag{37}$$

The remaining objective value is defined as the maximum of the future values of real and financial investment:

$$E_1^*\left[FV_T^{u,\tau}\right]_{t_I=1}=\max\left\{\left(1+r^\tau\right)^3,\ E_1\left[FV_T^{u,\tau}\right]\right\}$$
$$E_1^*\left[FV_T^{d,\tau}\right]_{t_I=1}=\max\left\{\left(1+r^\tau\right)^3,\ E_1\left[FV_T^{d,\tau}\right]\right\}. \tag{38}$$

The decision whether or not to delay investment is addressed in decision node 11 ($t=0$). The expected value of delayed investment can be written as:

$$E_0\left[FV_T^\tau\right]_{t_I=1}=p\ \ E_1^*\left[FV_T^{u,\tau}\right]_{t_I=1}+\left(1-p\right)\ \ E_1^*\left[FV_T^{d,\tau}\right]_{t_I=1}. \tag{39}$$

The expected future value of investing immediately is defined as the sum of the compounded operating cash flows of periods $t=1,\ 2$ and the remaining objective value in the decision nodes 31-38:

$$E_0\left[FV_T^\tau\right]_{t_I=0}=\left(1+r^\tau\right)^2 E_0\left[\pi_1^\tau\right]+\left(1+r^\tau\right)\ \ E_0\left[\pi_2^\tau\right]+E_0\left[E_2^*\left[FV_T^\tau\right]_{t_I=0}\right]. \tag{40}$$

Immediate investment is optimal if $E_0\left[FV_T\right]_{t_I=0}>E_0\left[FV_T\right]_{t_I=1}$. Again, the investor's initial expected objective value is the maximum of both terms:

$$E_0^*\left[FV_T^\tau\right]=\max\left\{E_0\left[FV_T^\tau\right]_{t_I=0};\ E_0\left[FV_T^\tau\right]_{t_I=1}\right\}. \tag{41}$$

6 Numerical examples in the after-tax case

Since the optimal investment timing and abandonment decisions after the integration of taxes are more complex and require more case differentiations than in the pre-tax model, analytical solutions are even more unlikely. Consequently, we focus on numerical simulations to elaborate the effects of (capital gains) taxation. The following examples illustrate the impact of introducing and varying the capital gains taxation on entrepreneurial investment and liquidation policy. Again, we focus on a symmetric distribution of upward and downward movements of the cash flow process ($p=\frac{1}{2},\ u=-d$).

The first example illustrates the impact of varying the pre-tax liquidation proceeds L_2 on the future values of immediate and delayed investment. Fig. 7 shows that the relative advantage of immediate versus delayed investment changes due to the introduction of capital gains taxation. Solid lines represent immediate investment, dashed lines delayed investment. Thick lines indicate after-tax values, thin lines values after ordinary taxation, but prior to capital gains taxation. For the parameter setting $d=0.2$, $r=0.1$, $\pi_0=0.2$ (left part of fig. 7), the investor prefers to invest immediately without capital gains taxation ($\tau^g=0,\tau^i=\tau^o=0.35$), if the liquidation proceeds exceed $L_2 = 0.625$. If capital gains are taxed, the investor will delay investment unless the liquidation proceeds reach at least $L_2 = 0.625$. Thus, capital gains taxation tends to favor delayed investment. Under this parameter setting, delayed real investment is never optimal. If the investor does not invest immediately, financial investment is preferred to delayed real investment.

However, this relation changes for higher pre-tax interest rates, e.g., for $r = 0.3$, as can be observed from the right part of fig. 7. Immediate investment will never be optimal after the introduction of capital gains taxation, because the investor always prefers to delay investment. For low values of L_2, financial investment is optimal, whereas delayed real investment maximizes the investor's future value for sufficiently high liquidation proceeds. Again, taxing capital gains favors delayed investment.

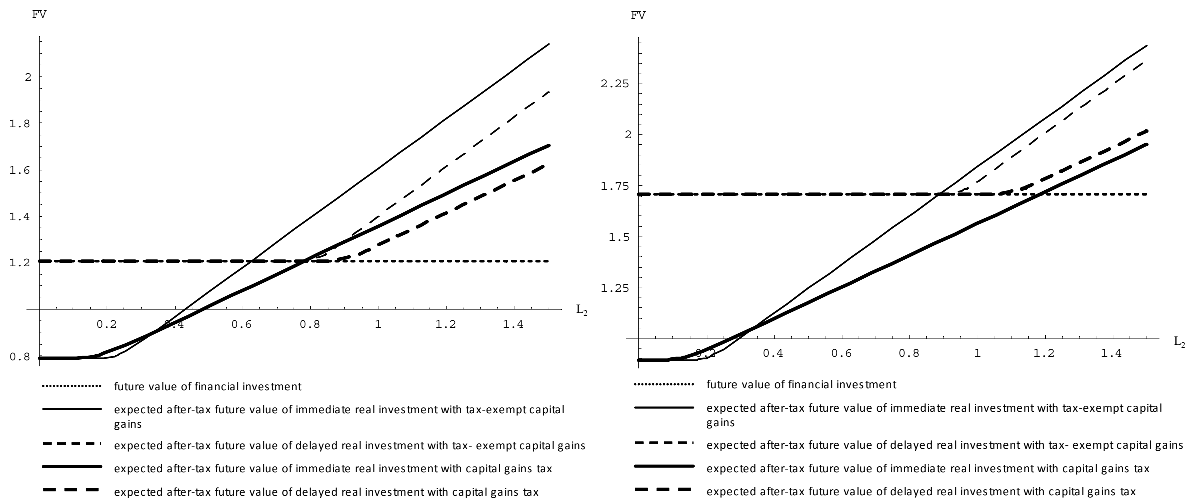

Fig. 7: Future values $E_0\left[FV_T^\tau\right]_{t_I=0}$, $E_0\left[FV_T^\tau\right]_{t_I=1}$ as functions of the liquidation proceeds L_2.

For $L_2 = \frac{1}{3}$ (immediate investment) and $L_2 = \frac{2}{3}$ (delayed investment), the taxable capital gain equals zero. The advantage of delayed investment under a capital gains tax is straightforward: The book value of assets to be offset against the constant liquidation proceeds L_2 in $t = 2$ equals $BV_2\big|_{t_I=0} = \frac{1}{3}$ in case of immediate investment and $BV_2\big|_{t_I=1} = \frac{2}{3}$ in case of delayed investment. The resulting capital gain $b_t^g\big|_{t_I=0} = L_2 - \frac{1}{3}$ exceeds the capital gain from delayed investment $b_t^g\big|_{t_I=1} = L_2 - \frac{2}{3}$. Consequently, immediate investment benefits to a higher extent from tax-exempt capital gains than delayed investment.

Varying the pre-tax interest rate r induces similar results as in the pre-tax case. For sufficiently low interest rates, immediate investment is optimal. If r exceeds a critical value, delayed real investment becomes beneficial. For sufficiently high interest rates, delaying investment and realizing financial investment in $t=1$ is the optimal alternative. Again, capital gains taxation favors delayed investment compared to immediate investment for positive capital gains. This effect is exemplified in fig. 8 for the parameter setting $L_2 = 1.25,\ u = -d = 0.2,\ \pi_0 = 0.375,\ \tau^g = \tau^i = \tau^o = 0.35$. The critical interest rate above which it is optimal to delay investment is $r = 0.554$ for $\tau^g = 0$, whereas it is $r = 0.413$ if capital gains are taxed at the rate $\tau^g = 0.35$. These critical interest rates can be observed from the intersections of $E_0\left[FV_T^\tau\right]_{tI=0}$ and $E_0\left[FV_T^\tau\right]_{tI=1}$.

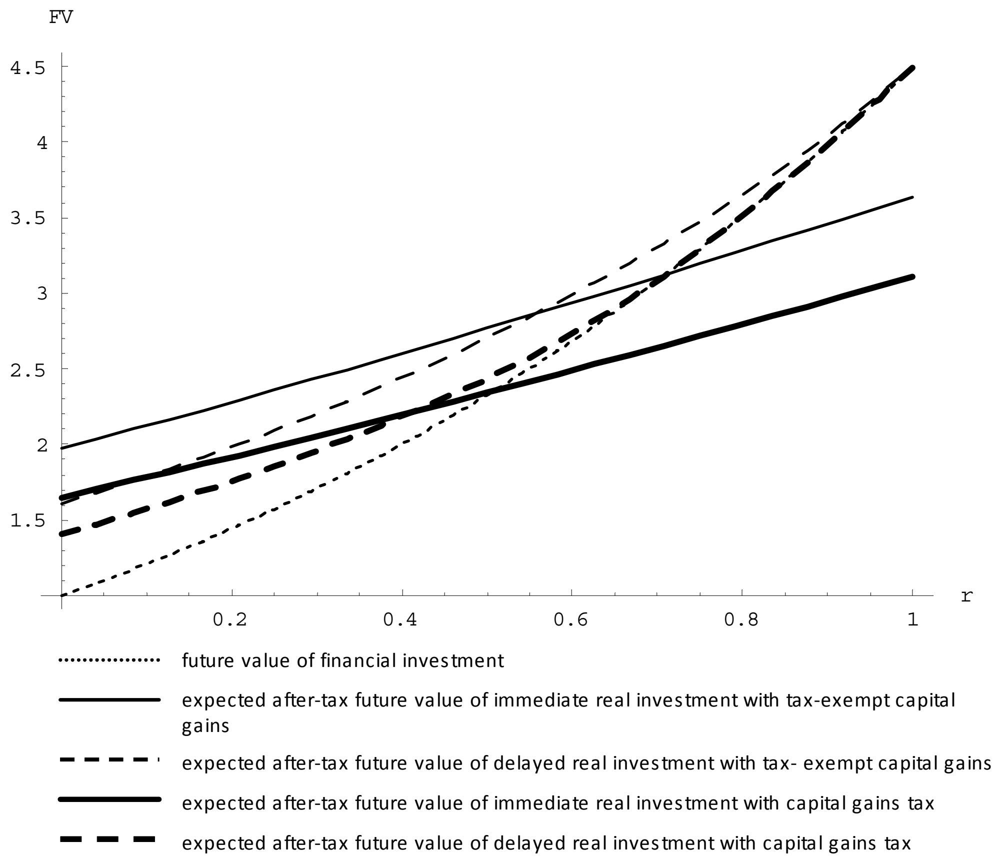

Fig. 8: Future values $E_0\left[FV_T^\tau\right]_{tI=0}$, $E_0\left[FV_T^\tau\right]_{tI=1}$ as functions of the pre-tax interest rate r.

Financial investment is never subject to capital gains taxation in our model. Thus, taxing capital gains tends to make real investment less attractive. The optimal switch from delayed real investment to financial investment depending on the pre-tax interest rate cannot be directly observed from fig. 8. It depends on the state of the cash flow process in $t=1$. Assuming an upward movement ($\pi_1 = \pi_1^u$), the investor never carries out real investment for $r > 1.014$ if capital gains are tax-exempt. For $\tau^g = 0.35$, this critical threshold decreases to $r = 0.7$ implying that real investment becomes less likely to be realized. Correspondingly, the critical interest rate for a downward movement in $t=1$ ($\pi_1 = \pi_1^d$) declines from $r = 0.864$ to $r = 0.55$, if the capital gains tax rate is increased from $\tau^g = 0$ to $\tau^g = 0.35$. As a result, immediate as well as delayed real investment suffer from capital gains taxation.

Varying the volatility of cash flows, measured by the difference of upward and downward movement $u-d$, yields the following future values as displayed in fig. 9, based on the parameter setting

$L_2 = 0.7,\ r = 0.1,\ u = -d,\ \pi_0 = 0.375,\ \tau^g = \tau^i = \tau^o = 0.35$:

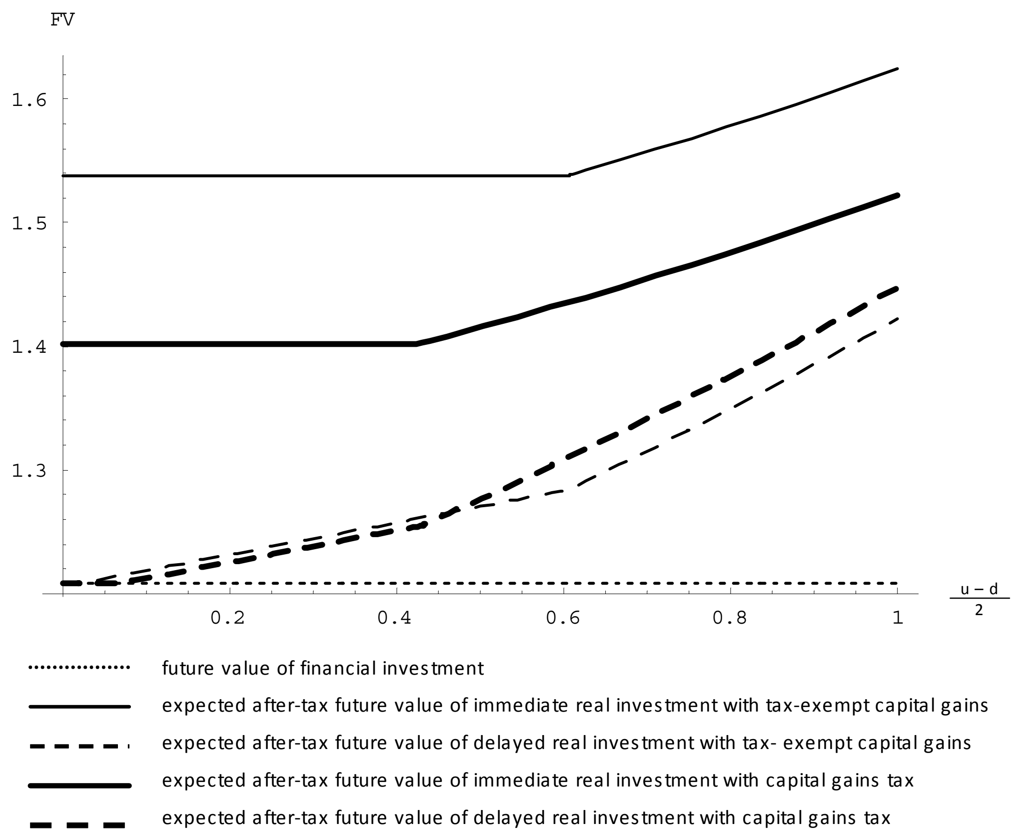

Fig. 9: Future values $FV_T^{fin,\tau}$, $E_0\left[FV_T^{\tau}\right]_{tI=0}$, $E_0\left[FV_T^{\tau}\right]_{tI=1}$ as functions of the upward movement $(u-d)/2$.

Since the upward and downward movements are symmetric ($u=-d$, $p=\frac{1}{2}$) the future values of real investment increase with increasing u. As can be seen from the intersection of the dashed lines, introducing capital gains taxation can increase the future value of delayed investment, even for positive capital gains. This paradoxical effect will be explained later on. With capital gains taxation, the kinks in the value functions for real investment can be observed for smaller values of u than without capital gains taxation. This effect is straightforward, because taxing capital gains penalizes liquidation more heavily than continuing the business. Thus, the critical values of u above which continuation is optimal decrease due to the introduction of capital gains taxation. Again, fig. 9 reveals that immediate investment suffers more from capital gains taxation than delayed investment, whereas financial investment remains unaffected.

Varying the capital gains tax rate τ^g induces ambiguous results with respect to optimal investment behavior. Since the capital gain for immediate investment is higher than for delayed real investment, increasing the capital gains tax rate relatively favors delayed investment. In special cases, the expected future value of delayed investment can even increase with increasing τ^g. This paradoxical effect is displayed in the left part of fig. 10 for the parameter setting

$L_2 = 0.7,\ u = -d = 0.2,\ r = 0.1,\ \pi_0 = 0.375,\ \tau^i = \tau^o = 0.35$.

As before, solid lines represent immediate investment, dashed lines delayed investment, and dotted lines financial investment.

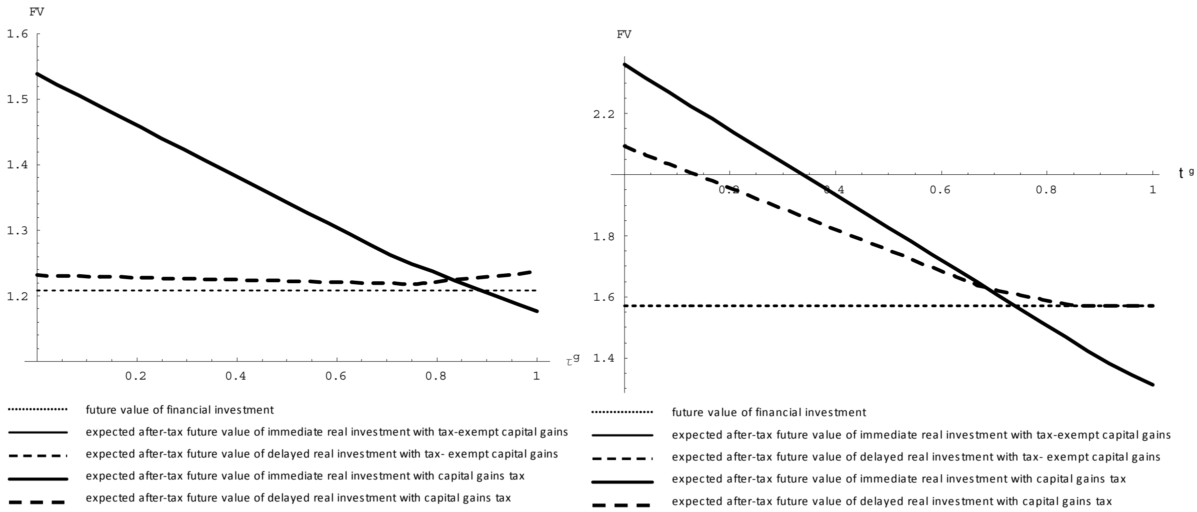

Fig. 10: Future values $FV_T^{fin,\tau}$, $E_0\left[FV_T^{\tau}\right]_{tI=0}$, $E_0\left[FV_T^{\tau}\right]_{tI=1}$ as functions of the capital gains tax rate τ^g.

Although the capital gain is always positive – the liquidation proceeds $L_2 = 0.7$ exceed the book values $BV_2\big|_{tI=0} = \frac{1}{3}$ and $BV_2\big|_{tI=1} = \frac{2}{3}$, respectively – the expected future value of delayed investment increases with increasing τ^g. This is due to the fact that the second term $\left(1-\tau^o\right)\ \pi_2 q + \frac{\tau^o}{3} + \frac{\tau^g}{3}$ in the maximum operation of (32) is increasing in τ^g and dominates for very high tax rates ($\tau^g > 0.7532$).[15] It depends on the parameter setting under consideration whether this effect occurs in the relevant tax rate interval $\tau^g \in [0,\ 1]$.

For $L_2 = 1.25,\ u = -d = 0.2,\ r = 0.25,\ \pi_0 = 0.375,\ \tau^i = \tau^o = 0.35$ both immediate and delayed investment suffer from increasing capital gains taxes, although delayed investment is penalized more heavily. This effect can be seen from the right part of fig. 10.

Hence, the optimal investment timing and liquidation decisions strongly depend on the capital gains tax rate. Typically, both types of real investment are discriminated by capital gains taxation compared to financial investment, but there exist exceptions with apparently paradoxical tax effects.

Summarizing, there is a wide variety of different economic effects due to variations of the pre-tax parameters and the capital gains tax rate.

7 Economic implications

We analyze the impact of capital gains taxation on optimal investment timing and abandonment policy under uncertain cash flows. A key feature of our model is entrepreneurial flexibility and partial irreversibility of investment. These properties of a real-world investment environment are modeled simultaneously by an option to invest and an option to abandon. Thus, an investor has the opportunity to choose between either investing immediately or postponing investment until the next period. Once an investment project is in place, the investor is not bound to the project until infinity. Rather, there exists an option to abandon the project prematurely.

Due to the interdependencies of the investment and liquidation decision, even the pre-tax model is rather complex. Since integrating taxes substantially increases the degree of complexity of the optimal simultaneous investment and abandonment decisions, analytical solutions are even more unlikely. To derive the model's main economic implications, extensive numerical simulations are necessary. We find that varying the liquidation proceeds affects the decision whether or not to postpone the investment decision. This result implies that a possible liquidation has to be anticipated at the date of investment. However, for a project already in place the date of investment does not matter for the liquidation decision. Increasing the pre-tax interest rate favors financial investment over real investment. Since delayed real investment includes a substantial financial investment component, immediate investment suffers more intensively from increased interest rates than delayed investment. This result corresponds to traditional investment theory. Higher cash flow

[15] This effect is even more obvious in case of capital losses. Then the loss-induced reimbursement increases with increasing τ^g.

volatility, measured by the dispersion of upward and downward movements, also favors delayed investment. This effect is in line with real option theory: The higher the volatility, the higher the value of the option to invest, thus, the lower the propensity to exercise the option by investing immediately.

These general economic effects can be confirmed after the integration of taxes. As a first result, integrating taxation complicates the analysis substantially.[16] Moreover, our model provides additional insights about the impact of differential taxation of interest income, ordinary business income, and capital gains. Compared to the case of tax-exempt capital gains, the introduction of capital gains taxation tends to be harmful for immediate investment. Since financial investment in our model is unaffected by capital gains taxation, the tax burden can only fall on real investment.

The capital gain for immediate investment exceeds the one for delayed investment. Thus, immediate investment is always discriminated more heavily than delayed investment. Of course, this effect is largely due to the assumption of constant liquidation proceeds, which are unaffected by the date of investment. However, other assumptions about the development of the liquidation proceeds over time would be either arbitrary or would require very complex asset pricing models that are incompatible with the individual calculus considered here.

Apart from the bias of capital gains taxation against real investment and especially immediate real investment, which is a straightforward economic effect, it should be noted that taxing capital gains may induce a tax paradox for delayed investment. Depending on the pre-tax parameter setting the future value of delayed investment may even increase in absolute terms for increasing capital gains tax rates, because due to the tax reimbursement at the end of the time horizon the future value from continuing the project increases with increasing capital gains tax rate. This effect is more likely to occur for low liquidation proceeds.

The conclusions mentioned above focus on the investment timing decision. This decision requires the anticipation of the optimal abandonment decision. If an investor decides upon liquidation of a project already in place, capital gains taxation should be considered, too. For given liquidation proceeds, which are sufficiently high, capital gains taxation tends to favor continuation of a project, because the taxable capital gains are higher than if the investor waits until the time horizon. For low liquidation proceeds leading to a capital loss, which entitles to a tax reimbursement, the effect is vice versa.

We illustrate the investment and liquidation effects of repealing the current exemption of capital gains in some countries and the effects of differential taxation of different classes of income. It is not the aim of this paper to provide conclusions about the desirability of capital gains taxation, because it is the tax legislator's duty to assess

[16] The effect of tax-induced complexity can be observed exemplarily from Hundsdoerfer/ Kruschwitz/Lorenz (2008).

whether the revealed economic consequences are regarded acceptable. For normative statements, a neutral reference case would be needed as a yardstick for identifying tax distortions. The reference case in our model is the status quo of tax-exemption of certain capital gains, not a hypothetical neutral tax. It is evident that exemption is not neutral with respect to investment and divestment decisions. Distortive effects of capital gains taxes are particularly likely as long as the taxation of ordinary income is not neutral. Against the background that real-world tax system usually are not neutral we find taxing capital gains would mainly induce other, but not necessarily less arbitrary distortions than exempting capital gains.

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Impressum:
Arbeitskreis Quantitative Steuerlehre, arqus, e.V.
Vorstand: Prof. Dr. Jochen Hundsdoerfer,
Prof. Dr. Dirk Kiesewetter, Prof. Dr. Caren Sureth
Sitz des Vereins: Berlin

Herausgeber: Kay Blaufus, Jochen Hundsdoerfer, Dirk Kiesewetter, Deborah Knirsch, Rolf J. König, Lutz Kruschwitz, Andreas Löffler, Ralf Maiterth, Heiko Müller, Rainer Niemann, Caren Sureth, Corinna Treisch

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ISSN 1861-8944