Investment timing effects of wealth taxes under uncertainty and irreversibility

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Abstract
We analyze the impact of wealth taxes on investment timing decisions under uncertainty and irreversibility by employing a real options model of the Dixit/Pindyck type. Considering that wealth taxes have been (re-)introduced or are under discussion in many countries, investors need decision rules for tax systems with wealth taxation. We integrate different valuation methods for wealth tax purposes, distinguish between broadly and narrowly defined wealth taxes and vary the wealth tax rate to ascertain which wealth tax design is more or less likely to accelerate or delay investment. Our main findings are threefold. First, historical cost valuation reduces the distortive timing effects of wealth taxation compared to fair value accounting. Second, broadening the wealth tax base tends to accelerate investment during high interest rate periods and delay investment during low interest rate periods. Our results predict that wealth taxes with a broad tax base are likely to discourage risky investment in times of near-zero interest rates. These distortive wealth tax base effects, however, can be avoided by granting sufficiently high depreciation deductions for wealth tax purposes. Third, the investment timing effects of wealth tax rate variations are very sensitive to the riskiness of the underlying investment. Moreover, investment timing effects crucially depend upon the depreciation rate for wealth tax purposes. A tax legislator who aims to encourage risk taking should introduce generous depreciation deductions. Our study indicates that if a wealth tax is considered to be politically inevitable, possible harmful investment effects can be mitigated by choosing appropriate valuation methods and parameters.

Keywords Wealth tax · Investment decisions · Real options · Timing flexibility · Uncertainty · Irreversibility

JEL Classification H25 · H21
1 Introduction

We analyze the impact of wealth taxes on investment timing when investment is irreversible and the future cash flow generated by the investment is uncertain. While a vast body of literature studies the impact of profit taxes on investment little is known about the impact of wealth taxes on investment timing. This is surprising as investment timing is an important indicator for an investor’s propensity to carry out risky projects. As investors are usually flexible with their choice on investment time, this flexibility generates an economic value (option to invest) that has to be compensated by future cashflows from the investment. Therefore, this option value and the resulting tax consequences have to be considered in the decision making process to avoid unprofitable investments. Also, there is currently a lively tax policy debate on the reintroduction of general wealth taxes in several countries. Many countries consider wealth taxes as an integral element of their tax system, either on an individual or corporate level, even though wealth taxes are known to distort investment decisions. Moreover, almost all countries levy taxes on specific assets, such as real estate, vehicles, or individual or corporate property. Investors, therefore, need decision rules for tax systems that include wealth taxes and tax politicians need to know how the design of a wealth tax affects investment behavior. Wealth taxes cannot be expected to exert effects identical to those that profit taxes do in related settings. This is because a wealth tax features components such as the valuation method, which are unknown to profit taxes, but are likely to crucially impact the value of the option to invest under wealth taxation and the wealth tax base. We will show that the direction of this wealth tax effect on investment timing is very sensitive to the risk-level involved and the overall design of the wealth tax.

Since the late 1990s, the effects of profit (or income) taxation under uncertainty have been extensively analyzed (for example, Niemann 1999a, b; Sureth 1999, 2002; Pennings 2000; Agliardi 2001; Panteghini 2001, 2004, 2005; Niemann and Sureth 2004, 2005, 2013; Alvarez and Koskela 2008; Schneider and Sureth 2010; Gries et al. 2012). However, the effects of wealth taxes have not yet been investigated under conditions of uncertainty and irreversibility. Prior literature identified parameter-dependent, partially subsidizing as well as discriminating effects of profit taxation on risky investments that are due to uncertainty (for example, Alvarez and Koskela 2008; Schneider and Sureth 2010; Gries et al. 2012; Niemann and Sureth 2013). These findings indicate that tax reforms, such as tax rate cuts, which are intended to foster investment, may have dysfunctional effects on investment activities particularly in high-risk industries. However, it is unclear whether wealth taxes will exert similar effects on investment timing. Although wealth taxes are often considered to hinder risky investment further, hardly any corresponding research on wealth taxation under uncertainty has been conducted.

There are few theoretical, conceptual or empirical studies on different property tax systems or other asset-specific taxes that identify distortive effects. Vlassenko

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1 For an overview see Appendix A.
(2001), Arnott (2005), Arnott and Petrova (2006) identify distortions in efficiency of different magnitudes depending upon the property tax design, but abstract from risk taking and timing issues. Dye et al. (2001) study empirically the impact of property taxes on business activities and find that high property tax rates lead to significantly slower growth rates. Craft and Schmidt (2005) find evidence for significant decreases in vehicular capital investment after changes in vehicle property taxes. In line with that result Allee et al. (2015) find significant sensitivities of petroleum refineries in their crude oil inventories when they experience a personal property tax. Key and Lightner (2015) find a negative relation between commercial values and property taxes. Hansson (2008) analyzes the abolishment or suspension of general wealth taxation in Austria in 1994, in Denmark in 1997, in Germany in 1997, and in the Netherlands in 2001 empirically using a simple model of the choice between becoming an entrepreneur or an employee. She finds a small but perceptible impact of wealth tax abolishment on entrepreneurial activity. Recently, Jakobsen et al. (2018) provide evidence from Denmark for the considerable impact of wealth taxes on capital accumulation. However, the existing empirical studies do not permit to draw clear-cut conclusions regarding the impact of wealth taxes on investment behavior. None of the studies discussed investigate the impact of uncertainty in conjunction with wealth taxes on risky investment explicitly.

In deterministic models, the impact of wealth taxes on investment behavior was analyzed within the German analytical tax literature of the 1980s and 1990s, for example, by Wagner and Dirrigl (1980), Siegel (1982), Mellwig (1985), or Georgi (1994). They find that wealth taxation has an ambiguous impact on investment decisions, depending upon the valuation of assets for wealth tax purposes. The effects of wealth taxes on risk taking were analyzed by Stiglitz (1969) who shows in a portfolio selection model that increases in wealth taxes increase risk taking for increasing relative and absolute risk aversion. However, these works do not consider timing flexibility.

To the best of our knowledge only van Wijnbergen and Estache (1999) investigate the impact of a special case of wealth taxes under uncertainty and flexibility explicitly. They examine the impact of a minimum asset tax, which is similar to a wealth tax, on high risk firms using an option pricing approach and a Monte Carlo simulation with Brazilian data. They consider uncertain returns and find increased sectoral distortions and also that high risk firms do not seem to be hit harder by the underlying tax. Under specific conditions, the introduction of the minimum asset tax may even lower the marginal effective tax rates. Their results are in line with the wealth tax paradox that has been elaborated under certainty in Sureth and Maiterth (2008). However, until now, no study has been conducted that addresses the investment and timing effects of a wealth tax in a stochastic environment with random cash flows. Particularly, as studies on the recently proposed tax on corporate and individual wealth in Germany indicate severe distortions (Spengel et al. 2013; Hoppe et al. 2016), the investment effects have to be analyzed prior to discussing potential distributional consequences. For example, Hoppe et al. (2016) find in their company data-based simulation that on average 15% of corporations’ equity is lost after six years of wealth taxation implying high risk for firms and jobs.
As a wealth tax lowers the value of real investment as well as the default alternative (i.e., financial investment), its effect on an investor’s propensity to invest in a risky real project is ambiguous. We extend the Dixit/Pindyck real option framework and assume that the investor can choose to defer the investment or conduct it immediately. Hence, investing immediately has an additional cost: the investor loses the option to wait and thus condition their decision on future cash flow realizations. We derive neutral tax systems that can serve as the benchmark case against which real-world tax systems can be compared. Neutral tax systems, therefore, are a helpful starting point to design wealth taxes.

The main results of our paper are as follows. From the investors’ perspective, we show that neglecting wealth taxation is typically harmful. We are the first to show that historical cost valuation tends to reduce the distortive timing effects of wealth taxation compared to fair value accounting. We find that broadening the wealth tax base by extending the tax base to include financial assets tends to accelerate investment during periods of high interest rates and to delay investment during periods of low interest rates, making wealth taxes a threat to economic growth, especially in times of zero interest rates. This distortive wealth tax base effect can be avoided by granting sufficiently high depreciation deductions for wealth tax purposes. We find that an increase in the wealth tax rate can either delay (hinder) or accelerate (foster) risky investments. In terms of risk taking this result implies that higher wealth tax rates can either stimulate or depress the propensity to invest in risky projects. As an example, accelerated investment upon a wealth tax increase is likely for low levels of wealth taxation and especially for low interest rates and for high-risk investments such as start-up firms. If increasing the tax rate is expected to distort investment timing to an undesired extent, i.e., investment is delayed (accelerated) too much, it is possible to mitigate or even reverse these effects by higher (lower) depreciation deductions. Our results indicate that a tax legislator who, besides distributive aims, additionally aims to encourage risk taking should define a relatively small wealth tax base. To summarize, if a wealth tax is considered politically desirable, potential harmful investment effects can be mitigated by choosing appropriate valuation methods and parameters. Our results are driven by asymmetric impacts of wealth taxes on the three drivers of the investment decision: the investment project, the default alternative, and the option value embedded in investors’ timing flexibility.

Although our model primarily addresses individual investment behaviour, our findings are also relevant for the current tax policy discussion on the (re-)introduction of wealth taxes. As changes in investment behaviour affect profits and job creation, tax legislators should be aware that the investment effects are highly parameterspecific and depend upon the expected development of pre-tax profits, as well as the

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2 For example, the IMF suggested the introduction of wealth taxes in developed countries in various recent studies (IMF 2013; IMF 2014). Furthermore, Atkinson (1971), Saez and Veall (2005), Piketty (2014), Auerbach and Hassett (2015). See, for example, Cnossen and Bovenberg (2001) for the Netherlands, Edson (2012) for Norway, Glennerster (2012) for U.K., Keuschnigg et al. (2013) for Austria, Sureth and Maiterth (2008), Maiterth and Houben (2012), Spengel et al. (2013), Bach et al. (2014), Hoppe et al. (2016) for Germany.
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valuation of assets for income and wealth tax purposes. A tax legislator who introduces or increases wealth taxes for distributional reasons typically intends to restrict potential distortions of real investments and thus needs to be aware of these effects. By deriving testable hypotheses regarding the timing effects of different wealth tax parameters, our paper paves the way for future empirical studies of investment timing under wealth taxation.

This paper is organized as follows. We present our investment model in Sect. 2 and derive neutral tax systems in Sect. 3. The impact of varying wealth tax parameters is analyzed in Sect. 4. Section 5 summarizes and concludes.

2 Model setup

Our model of investment is based on the Dixit and Pindyck (1994) framework that is widely used for the analysis of tax and non-tax effects under uncertainty and irreversibility. We contribute to this stream of the literature by integrating timing effects of wealth taxation that have not been addressed so far, so that our model fits accurately into the research gap described above. Given that real-world investment decisions are typically now-or-later rather than now-or-never decisions, a real option framework with timing flexibility is appropriate for analyzing the impact of taxation on investment. A continuous-time model with a continuous state space is ideal to analyze wealth tax effects, because the impact of parameter variations on investment behavior can be analyzed more subtly and in greater detail than in discrete models. A discrete-time model would be limited to corner solutions, so that the investment timing decision would collapse to a binary decision and the magnitude of different tax effects would not be easily observable. Apart from its wide distribution in the academic literature, the Dixit/Pindyck real options framework is well-established in business practice, especially in commodity-related industries such as oil, gas, mining, and forestry.

We assume that a risk-neutral investor has the option to invest in a real investment project with stochastic operational cash flows. The option to invest is a proprietary business opportunity, which is due to past activities of the investor (or firm). Whereas all real options considered here are proprietary options, it is necessary for tax purposes to distinguish further between acquired and non-acquired real options.

We focus on non-acquired options, which are a common feature of many investments that by their nature offer additional flexibility in the future. Non-acquired options can be due to investment projects that have been carried out in the past or by simply gaining experience while doing business in a specific market or industry. At the point in time when the real option emerges, the investor might not even be aware of creating a real option. Such a non-acquired option is not an asset that can be recognized or traded. Rather, the option value is a technical construct that is needed for determining the optimal investment timing decision. A non-acquired option does not directly affect taxable income and wealth, because no single past payment or activity can be directly attributed to such a real option. Therefore, non-acquired real options must not be capitalized and do not entitle to depreciation deductions, cannot be included in the wealth tax base and do not trigger any tax payments. As a
consequence, the cash flow that is attributable to a non-acquired real option always equals zero. Models with non-acquired options often permit closed-form solutions of the investment problem. Although non-acquired real options are neglected for tax purposes, the option value is tax-dependent, because the underlying asset—the investment project—as well as the interest rate are taxable.

In contrast, acquired real options such as exploration rights, licences or patents are assets in a legal sense and as such can influence the tax base directly via depreciation deductions or inclusion in the wealth tax base. Thus, acquired real options can induce tax payments and hereby non-zero cash flows before exercising the option. However, models that take the tax consequences of acquired options explicitly into account typically cannot be solved analytically. Against this background and in the light of the inherent flexibility created by many investment opportunities, it seems reasonable to focus on non-acquired real options.

The distinction between acquired and non-acquired real options was introduced by Niemann (1999a, b). This issue does not arise in the non-tax real options literature, because without taxes it is irrelevant how real options have been created in the past (sunk costs). From a pre-tax perspective, only flexibility for future decisions matters. Introducing taxation, however, past decisions can influence future tax payments.

A second crucial assumption refers to the lifetime of the option to invest. Although the lifetime of a business opportunity in the real world can be either finite or infinite, there exists no closed-form solution of the investment problem for options with finite expiration dates. Due to the fact that analyzing the impact of wealth taxes on investment timing requires closed-form solutions, we examine the case of a perpetual non-acquired option. It should be noted that this case represents an upper bound for the option value. We exclude competition effects, because the investor holds a proprietary option.

We further assume that the lifetime of the investment project is infinite. This assumption does not restrict generality and is for mathematical convenience only.

The value of the investment project is subject to wealth taxation. The profit from the investment is subject to profit taxation. The investor uses individual calculus for valuation of both the project and the option to invest. They can either immediately invest into the real investment project, or wait until the observable realizations of the cash flows prove to be sufficiently attractive. As long as the option to invest is not exercised, available funds yield the risk-free capital market rate. If the option to invest is exercised, the investor gives up all flexibility and pays the deterministic acquisition cost for the project. Without loss of generality, we normalize the acquisition cost to unity: $I_0 = 1$.

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3 Formally, these investment problems typically involve partial differential equations that can only be solved numerically.

4 For strategic option exercise games see, e.g., Grenadier (1996), Grenadier (2002), and Weeds (2002). Grenadier (2002) shows that the impact of competition substantially diminishes the value of the option and induces investment decisions similar to the net present value rule.
Given the volatility of asset prices and the potentially long time horizon until the option is exercised, the assumption of constant acquisition cost could appear unrealistic. It would indeed be possible to model cash flows and acquisition cost as correlated stochastic processes. In a model without taxes, Dixit and Pindyck (1994, pp. 207–211) show for the special case of two geometric Brownian motions that the critical investment threshold can be expressed as the ratio of cash flows and acquisition cost rather than simply as the level of cash flows. Technically, their investment rule is very similar to the simpler version used here, but would not provide additional tax-related insights. Integrating acquisition cost uncertainty would only add the correlation of the two stochastic processes to the decision rule, which is not the focus of our study and comes at the cost of less intuitively accessible results. In line with prior literature, for reasons of mathematical simplicity and to concentrate on wealth tax effects, we leave this interesting extension for future research.

We assume that the project is entirely equity-financed to separate the tax effects from investment and financing decisions. Since our model is based upon individual calculus, a valuation based on contingent claims analysis such as in financial option pricing is not possible. Thus, we do not need the spanning property, implying that liquid markets for the assets need not exist.

In contrast to traditional NPV calculus that only involves the investment project and the default alternative (i.e., financial investment), the tax treatment of the investment project, the option to invest, and the default alternative (wait and see and park funds in a risk-free financial capital market asset) have a potential impact on investment timing.

We consider only one level of taxation and thus abstract from the interaction of corporate and shareholder level taxation. This assumption means that the investor is either a sole proprietor or partner in a partnership (pass-through entity) or a corporation that neglects shareholder taxation in corporate decision making. We do not discuss delegated investment decisions or principal-agent settings.5

As long as the investor waits and does not (yet) invest, they earn the exogenously-given nominal risk-free pre-tax interest rate $r$ that is subject to income taxation at the rate $\tau_r \in [0, 1]$. The tax rates on interest income $\tau_r$ and on other business income $\tau_\pi \in [0, 1]$ can differ.6 Financial assets such as bank accounts or bonds that yield interest income are subject to wealth taxation at the flat rate $\tau_w \in [0, 1]$.

The variable $\gamma \in [0, 1]$ denotes the fraction of these financial assets that is subject to wealth taxation. Thus, $\gamma$ defines the broadness of the wealth tax base. It permits to include different special cases such as tax-exempt financial assets ($\gamma = 0$) or partially taxable financial assets ($0 < \gamma < 1$) in the model. The case of a tax on special assets such as real estate or vehicles can be represented by a narrow tax base with the parameter $\gamma = 0$. In contrast, a general wealth tax comprising all real and

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5 For delegated investment decisions in a real options setting see, e.g., Grenadier and Wang (2005).

6 Many European and Asian countries are characterized by tax systems with different tax scales on interest and dividend income on the one hand side and other income (business, labor, etc.) on the other hand side. By contrast, the tax systems in the Americas are typically characterized by a uniform tax rate on all types of income.
financial assets is characterized by a broad tax base $\gamma = 1$. Thus, the parameter $\gamma$ will be a pivotal determinant for the concept of wealth taxation in our model.\(^7\)

As a consequence, the discount rate after taxes is defined as $r_\tau = (1 - \tau_r) r - \gamma \tau_o > 0$. We must assume that this after-tax discount rate is strictly positive, otherwise present values could reach economically meaningless infinite values.

If the investor decides to exercise the option to invest and acquires the investment project, they lose any further timing flexibility. There is, however, no obligation to invest. If the project conditions are not sufficiently favorable the investor could theoretically postpone the decision until infinity. The investor waits until $\pi$ becomes sufficiently large. Once the project is in place there is no more additional flexibility so its only benefit is the value of the future operating cash flows $\pi$. Taking into account the investor’s risk neutrality, the value of the investment project is simply its expected present value.

The stochastic operating cash flows $\pi$ are subject to income taxation. Depreciation $d_{\pi}(t)$ can be deducted from the income tax base. For analytical simplicity we assume that depreciation deductions for income tax purposes are based upon the acquisition cost of the project and decrease exponentially at the rate $\delta_{\pi}$.\(^8\) Taxation is assumed to be symmetric, which means that a full and immediate loss-offset is available.

In a second step, the wealth tax must be subtracted. If the wealth tax base at time $t$ is given by $W(t)$,\(^9\) and the wealth tax is not deductible from the profit tax base, total cash flow after taxes at time $t$ is

$$
\pi_\tau(t) = \left(1 - \tau_{\pi}\right) \pi(t) + \tau_{\pi} \delta_{\pi} e^{-\delta_{\pi} t} - \tau_o W(t).
$$

Since our model takes an individual rather than a general equilibrium perspective, the investor takes the pre-tax cash flow to be exogenously given. We assume that the existence of the tax system as defined here does not affect pre-tax cash flows or the pre-tax interest rate.\(^10\)

For further results the cash flow process must be defined. In accordance with prior literature (for example, McDonald and Siegel 1985; Dixit and Pindyck 1994; Niemann 1999b; Sureth 2002; Niemann and Sureth 2004, 2005) we assume that the pre-tax cash flow $\pi$ follows a geometric Brownian motion $d\pi/\pi = \alpha dt + \sigma dz$, with $\alpha < r_\tau$ as the expected growth rate of cash flows, $\sigma$ as the volatility rate, and $dz$ as increment of a standard Wiener process. Taking into account the expected pre-tax

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\(^7\) The concept of “broadness” as defined by the parameter $\gamma$ has to be distinguished from a tax base that can be high or low due to deductions such as depreciations allowances.

\(^8\) This assumption does not restrict generality, because any other depreciation schedule such as straight-line depreciation or double-declining balance depreciation can be transformed into exponential depreciation in identical present value terms. A similar approach is used in analytical models of effective tax rates, e.g., by King and Fullerton (1984, p. 29).

\(^9\) In our notation, $W(t)$ is the wealth tax base and does not refer to a Wiener process whose increments are denoted by $dz$ here.

\(^10\) With respect to the effect of a wealth tax rate on the rate of interest see, e.g., Atkinson (1971, p. 217).
cash flow at time $t$ after investment $E[\pi(t)] = \pi(0)e^{at} = \pi_0 e^{at}$ permits to write the project value as

$$V_t = E\left[\int_0^{\infty} \pi_t(t)e^{-r_t t}dt\right] = \left(1 - \tau_\pi\right)\pi_0 + \frac{\tau_\pi \delta_\pi}{\delta_\pi + \tau_\pi} - \tau_\omega \int_0^{\infty} E[W(t)]e^{-r_t t}dt. \tag{2}$$

Thus, the project value is defined as the sum of the expected present value of cash flows after income taxes and tax savings due to depreciation deductions for income tax purposes, less the expected present value of wealth tax payments.

With regard to the wealth tax base we have to distinguish two general concepts: fair value accounting (henceforth FV) and historical cost accounting (henceforth HC). Whenever we use the terms “fair value accounting” or “historical cost accounting”, we refer to accounting for tax purposes rather than financial accounting which is not considered in this paper. While in many countries wealth taxes are based upon the fair value or market value of a taxpayer’s wealth, meaning that wealth tax payments necessarily fluctuate over time, some countries look at historical acquisition cost or historically assessed values of the wealth or property to reduce complexity and compliance problems. As a consequence, under HC, wealth tax payments are predictable at the time of investment. As prior literature on property taxation indicates that the valuation method is crucial for the investment effects of non-profit taxes (Bentick 1979; Arnott 2005; Arnott and Petrova 2006), we account for both concepts.

Under HC for tax purposes the initial wealth tax base equals some predefined constant $W_{HC}$. The acquisition cost is the most important special case for the initial value. It is also possible, however, that the initial value of an asset for wealth tax purposes is unrelated to acquisition cost or market price. This is current tax practice for assets in some jurisdictions.\textsuperscript{11}

Subsequent valuation under HC is a function of the initial value $W_{HC}$. Similar to the valuation for income tax purposes, under HC we assume that the value for wealth tax purposes is written off exponentially at the rate $\delta_\omega$: $W_{HC}(t) = W_{HC} \cdot e^{-\delta_\omega t}$.\textsuperscript{12} The depreciation parameter $\delta_\omega$ is not necessarily positive so increasing or constant values are also possible. To avoid infinite present values we require only that $\delta_\omega > -r_\tau$ holds. Under these assumptions the project value simplifies to

$$V_{HC} = \frac{(1 - \tau_\pi)\pi_0}{r_\pi - \alpha} + \frac{\tau_\pi \delta_\pi}{r_\pi + \delta_\pi} - \frac{\tau_\omega W_{HC}}{r_\tau + \delta_\omega}. \tag{3}$$

\textsuperscript{11} The real estate tax (Grundsteuer) in Austria and in Germany can serve as an example for an arbitrary valuation, because the assessed tax value (Einheitswert) is neither based on acquisition cost nor on market value. The Austrian Constitutional Court even decreed the abolishment of the Austrian estate tax due to the (extremely) unequal valuation of real estate compared to other assets. See Verfassungsgerichtshof Österreich (2007).

\textsuperscript{12} Again, any other depreciation schedule can be replicated by exponential depreciation in present value terms. Hence, the assumption of exponential depreciation does not restrict generality.
Under FV, however, the initial wealth tax base should refer to the present value of the project at the time of acquisition. Since market values need not exist for each asset, it is common practice for the fiscal authorities to use multiplier methods based on current cash flows, or even historical cash flows from financial statements to approximate market values (for example, Müller and Sureth 2011; Müller 2014). Although this valuation approach does not exactly reflect FV in a financial accounting sense, it is very similar to FV in expected present value terms. Therefore, we continue to use the term FV for ease of presentation. We assume that the fiscal authorities use a multiplier \( f(\rho) = 1/\rho > 0 \) for wealth tax purposes to compute the project’s initial value \( \bar{W}_{FV} = \pi_0/\rho \). The growth and discount rates of the investor and the tax authorities need not coincide, \( \rho \geq (r_\tau - \alpha) \). As with HC, the subsequent value for wealth tax purposes is written off exponentially at the rate \( \delta_\omega > -r_\tau \). Consequently, the project value under FV is given by

\[
V_{FV} = \frac{(1 - r_\tau)\pi_0}{r_\tau - \alpha} + \frac{r_\tau \delta_\pi}{r_\tau + \delta_\pi} \pi_0 \cdot \frac{\tau_\omega}{r_\tau + \delta_\omega} .
\] (4)

In contrast to HC, the current value of the cash flow \( \pi_0 \) affects the present value of expected wealth tax payments in the third summand.\(^{13} \)

Given the values of the investment project, the option values and subsequently the optimal investment thresholds, i.e., the critical values of the cash flow process \( \pi \) at which the investor invests immediately can be determined.

**Proposition 2.1** Under HC/FV, the critical investment threshold is given by

\[
\pi_0^{HC} = \frac{\beta_\tau}{\beta_\tau - 1} \cdot \frac{r_\tau - \alpha}{1 - r_\pi} \left( 1 - r_\pi D_\pi + \tau_\omega D_\omega \right),
\] (5)

\[
\pi_0^{FV} = \frac{\beta_\tau}{\beta_\tau - 1} \cdot \frac{r_\tau - \alpha}{1 - r_\pi} \left( 1 - r_\pi D_\pi \right),
\] (6)

with \( D_\pi = \frac{\delta_\pi}{r_\tau + \delta_\pi} \), \( D_\omega = \frac{\bar{W}_{HC}}{r_\tau + \delta_\omega} \), \( \beta_\tau > 1 \).

**Proof** See Appendix 2.1.

Equivalent to (5), we can write

\[\pi_0^{HC} = \frac{\beta_\tau}{\beta_\tau - 1} \cdot \frac{r_\tau - \alpha}{1 - \tau_\pi} D_\pi \left( 1 - \tau_\pi D_\pi + \tau_\omega D_\omega \right),\]

\[\pi_0^{FV} = \frac{\beta_\tau}{\beta_\tau - 1} \cdot \frac{r_\tau - \alpha}{1 - \tau_\pi} \left( 1 - \tau_\pi D_\pi \right),\]

\[D_\pi = \frac{\delta_\pi}{r_\tau + \delta_\pi} \frac{D_\pi}{D_\pi}, \quad D_\omega = \frac{\bar{W}_{HC}}{r_\tau + \delta_\omega}, \quad \beta_\tau > 1.\]
Equation (7) can be interpreted as follows. The expected present value of after-tax cash flows must exceed the effective acquisition cost of a project by a multiple $\beta \tau / (\beta \tau - 1) > 1$ to cover the value of the option that is lost due to exercise. For high volatilities, this multiple substantially exceeds unity. It is obvious that neglecting the option value (such as under the traditional NPV rule) leads to premature investment. The effective acquisition cost comprises the gross acquisition cost $I_0 = 1$ less the present value of the tax shield of depreciation deductions for income tax purposes $\tau D_0^\pi$ plus present value of wealth taxes $\tau D_\omega$ to be paid during the infinite lifetime of the project. For $\tau_\omega = 0$ the critical threshold $\pi_0^{HC}$ from (5) is identical to the thresholds developed in earlier literature using income taxes only. Wealth taxation influences the critical threshold not only directly via the present value of wealth tax payments $D_\omega$, but also indirectly by altering the after-tax interest rate $r^\tau$ and the multiplier $\beta \tau / (\beta \tau - 1)$. As a consequence, wealth tax effects are not always straightforward as will be shown below.

Similar to the HC case, we can write (6) as

$$\frac{1 - \tau D_\omega}{r^\tau - \alpha} \cdot \pi_0^{HC} = \frac{\beta \tau}{\beta \tau - 1} \left( 1 - \frac{\tau D_\omega}{1 - \rho \tau + \delta \omega} \right) \cdot \left( \frac{1 - \tau D_0^\pi}{1 - \rho \tau - \alpha} \right) .$$

Again, the multiplier $\beta \tau / (\beta \tau - 1)$ indicates that the expected present value of the project has to compensate for the option value lost by exercise. The term $1 - \tau D_\omega$ represents the effective acquisition cost considering only income taxes, and the denominator in the second fraction on the right hand side includes the present value of wealth tax payments. In contrast to HC, wealth taxes under FV enter the critical investment threshold in a multiplicative rather than an additive way.

14 See, for example, Niemann and Sureth (2005, p. 82).


3 Neutral tax systems

Neutral tax systems serve as a reference case for detecting tax effects. By definition, neutral tax systems do not alter economic decisions compared to the pre-tax case. If a tax system is known to be neutral, taxpayers can save tax planning costs and stick to their decisions from the pre-tax scenario. In our setting, a neutral tax system leaves the critical investment threshold unchanged. For a non-acquired perpetual option, we are able to derive a necessary and sufficient neutrality condition by comparing the closed-form solutions for the critical investment threshold. As there are various tax parameters with potentially offsetting effects, there are an infinite number of neutral tax systems. Due to different investment thresholds for historical cost and fair value accounting, neutrality conditions have to distinguish between these valuation methods.

The pre-tax investment threshold as a benchmark is derived as a special case from (5) or (6) by setting all tax rates to zero: \( \tau_r = \tau_\pi = \tau_\omega = 0 \).

\[
\pi_0^* = \pi_0^{HC} \bigg| \tau_r=\tau_\pi=\tau_\omega=0 = \pi_0^{FV} \bigg| \tau_r=\tau_\pi=\tau_\omega=0 = \frac{\beta}{\beta - 1} (r - \alpha),
\]

with

\[
\beta = \beta_r |_{\tau_r=0} = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} \geq \beta_r > 1.
\]

**Proposition 3.1** Under HC/FV, the neutral present value of depreciation deductions for income tax purposes is given by

\[
D^{HC}_\pi = \frac{1}{\tau_\pi} \left[ 1 - \frac{\beta_r - 1}{\beta_r} \cdot \frac{\beta}{\beta - 1} \cdot \frac{r - \alpha}{r_\tau - \alpha} \cdot \left(1 - \tau_\pi\right) + \frac{\tau_\omega W^{HC}}{r_\tau + \delta_\omega} \right]
\]

\[
D^{FV}_\pi = \frac{1}{\tau_\pi} \left[ 1 - \frac{\beta_r - 1}{\beta_r} \cdot \frac{\beta}{\beta - 1} \cdot \frac{r - \alpha}{r_\tau - \alpha} \cdot \left(1 - \tau_\pi - \frac{\tau_\omega}{\rho} \cdot \frac{r_\tau - \alpha}{r_\tau + \delta_\omega} \right) \right]
\]

**Proof** Equating the critical investment thresholds from (5)/(6) and (9) and further transformation directly leads to (10) and (11).

These neutral PVs of depreciation deductions for income tax purposes are functions of the after-tax discount rate \( r_\tau \), the wealth tax rate \( \tau_\omega \), as well as the project-specific parameters \( \alpha \) and \( \sigma^2 \) and are therefore parameter-dependent. This implies that each and every investment project is characterized by its own neutral depreciation PV. A general neutral depreciation PV that holds independent of the characteristics of the investment project does not exist. If the actual depreciation PV for

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15 See Dixit and Pindyck (1994, p. 143).
investment tax purposes exceeds the neutral one, investment is accelerated. Otherwise, investment is delayed by wealth taxation.

Equations (10) and (11) further show that an increase in wealth taxation—for example due to an increase of $\hat{W}_{HC}$ or $\rho$ or a decrease of $\delta_{\omega}$—must be accompanied by a corresponding reduction of income taxes to preserve neutrality. This means that the neutral depreciation PV captures all arising tax effects simultaneously, including income and wealth taxation as well as neutral treatment of the option to invest, which requires taxation of unrealized capital gains.

Although it is always possible to find algebraic solutions for $D_{HC}^{\pi}$ and $D_{FV}^{\pi}$, it cannot be guaranteed that these are feasible within the range of real-world tax systems ($0 \leq D_{\pi} \leq 1$). Therefore, the analytically determined neutral tax system might be only theoretically relevant and de facto impossible to be implemented in the real world.

4 Investment timing effects of wealth taxation

Having determined the reference case of neutral tax systems, it is obvious that real-world tax systems will rarely be neutral. In this section we analyze how different wealth tax parameters affect investment timing by their effects on the critical investment threshold $\pi_{0}^{HC} / \pi_{0}^{FV}$. We focus on those tax parameters that induce ambiguous effects and that have not yet been analyzed in the real options literature. These parameters are the valuation method (HC versus FV), the broadness of the tax base defined by the taxable fraction of financial assets $\gamma$, and the wealth tax rate $\tau_{\omega}$.

In general, the choice of the valuation method by the tax legislator induces ambiguous effects on investment timing. Whether HC or FV are more likely to accelerate or delay investment depends upon the initial value $\hat{W}_{HC}$ and the multiplier $1/\rho$ as prescribed by tax law. By equating the critical investment thresholds for HC and FV and solving for the respective valuation parameter, it is possible to derive an initial valuation under HC $\hat{W}_{HC}$ (or a multiplier under FV $1/\hat{\rho}$) for which the investor is indifferent between both valuation methods. For $\hat{W}_{HC} > (<) \hat{W}_{HC}$ HC valuation would delay (accelerate) investment compared to FV.

**Proposition 4.1** The critical thresholds under historical cost valuation and fair value accounting are identical if and only if the following relation of $\hat{W}_{HC}$ and $\rho$ holds:

$$\pi_{0}^{HC} = \pi_{0}^{FV} \quad \Leftrightarrow \quad \hat{W}_{HC} = \frac{r_{\pi} + (1 - \tau_{\pi})\delta_{\pi}}{r_{\pi} + \delta_{\pi}} \frac{(r_{\pi} + \delta_{\omega})(r_{\pi} - \alpha)}{\rho(1 - \tau_{\pi})(r_{\pi} + \delta_{\omega}) - \tau_{\omega}(r_{\pi} - \alpha)}.$$  

If the multiplier used by the tax legislator is consistent with the interest rate and growth expectations used by the investor, i.e., $\rho = r_{\pi} - \alpha$, this expression simplifies to
which leads to

**Conjecture 4.2** For reasonable parameters FV tends to delay investment compared to HC.

If the depreciation rate for income and wealth tax purposes are identical (δ_ϊ = δ_ώ = δ > −r_τ), this implies that

\[
\hat{W}_{HC} \bigg|_{\rho = r_τ - \alpha} = \frac{r_τ + (1 - τ_κ)δ_κ}{r_τ + δ_κ} \cdot \frac{r_τ + δ_ώ}{(1 - τ_κ)(r_τ + δ_ώ) - τ_ω},
\]

where

\[
\begin{align*}
0 < 1 \quad &\quad \iff \quad \frac{r_τ + (1 - τ_κ)δ_κ}{(1 - τ_κ)(r_τ + δ_ώ) - τ_ω} > 1.
\end{align*}
\]

Hence, given this (not entirely unlikely) parameter setting, the indifference level for the initial value under HC exceeds the acquisition cost. This implies that HC, with an initial wealth tax value that equals acquisition cost, accelerates investment compared to FV. In other words, under HC a wealth tax tends to not be as harmful as under FV. However, this result is just a trend statement. The tax legislator is of course free to choose the initial tax value or the multiplier in a way that favors either HC or FV.

The tendency that a wealth tax under HC is less harmful than under FV follows from the real option-based decision rule that triggers investment only when the expected PV of a project (i.e., the wealth tax base under FV) exceeds its acquisition cost (i.e., the wealth tax base under HC) substantially. Under the traditional NPV decision rule that neglects the value of flexibility, this distinction between HC and FV cannot be observed.

**Proposition 4.3** Both broadening the wealth tax base by increasing γ and increasing the wealth tax rate τ_ώ induce ambiguous effects on investment timing, i.e.,

\[
\frac{\partial \pi_0^{HC/FV}}{\partial γ} \lessgtr 0
\]

\[
\frac{\partial \pi_0^{HC/FV}}{\partial τ_ώ} \lessgtr 0
\]

**Proof** To prove the existence of ambiguous results, it is sufficient to show that the partial derivatives \(\partial \pi_0^{HC/FV} / \partial γ\) and \(\partial \pi_0^{HC/FV} / \partial τ_ώ\) may take either algebraic sign for

\[
\begin{align*}
0 < 1 \quad &\quad \iff \quad \frac{r_τ + (1 - τ_κ)δ_κ}{(1 - τ_κ)(r_τ + δ_ώ) - τ_ω} > 1.
\end{align*}
\]
The effects of broadening the wealth tax base by varying the taxable fraction of financial assets \( \gamma \) depend on all included tax and non-tax parameters \( r, \alpha, \sigma, \tau_r, \tau_\pi, \tau_\omega \). Although the partial derivatives are generally too complicated to be studied analytically, numerical examples show that either algebraic sign is possible. Adding to prior reasoning on the wealth tax effects on investment decisions under certainty (Wagner and Dirrigl 1980; Siegel 1982; Mellwig 1985; Georgi 1994) we find unexpected effects of wealth taxation under uncertainty. In the following, we elaborate on which effect prevails under specific conditions. We define the effects of wealth taxation as “intuitive” if increasing wealth taxation of the investment project increases the critical investment threshold and thus delays investment, or if increasing wealth taxation of financial assets (default alternative) reduces the critical investment threshold, i.e., if \( \frac{\partial \pi_0^{HC/FV}}{\partial \tau_\omega} > 0 \) or \( \frac{\partial \pi_0^{HC/FV}}{\partial \gamma} < 0 \). Otherwise, for \( \frac{\partial \pi_0^{HC/FV}}{\partial \tau_\omega} < 0 \) or \( \frac{\partial \pi_0^{HC/FV}}{\partial \gamma} > 0 \), we call the emerging tax effects “counterintuitive”. Further computations of the partial derivatives \( \frac{\partial \pi_0^{HC}}{\partial \tau_\omega} \) and \( \frac{\partial \pi_0^{HC}}{\partial \gamma} \) in the limiting cases \( \sigma \to 0 \) (certainty), \( \sigma \to \infty, r \to \infty \) are included in Appendix D.

With respect to \( \gamma \), the occurrence of intuitive or counterintuitive wealth tax effects essentially depends upon the level of the after-tax discount rate. For sufficiently high after-tax discount rates \( r_r \), intuitive tax effects prevail. Hence, for high pre-tax interest rates, real-world levels of income tax rates \( \tau_\pi \) and \( \tau_\omega \), and low or moderate levels of the wealth tax rate \( \tau_\omega \), the partial derivatives \( \frac{\partial \pi_0^{HC}}{\partial \tau_\omega} \) and \( \frac{\partial \pi_0^{FV}}{\partial \gamma} \) are negative. This means that broadening the wealth tax base reduces the critical investment threshold and hence accelerates real investment. This effect is plausible because increasing \( \gamma \) does not affect cash flows from investment and only reduces the after-tax discount rate \( r_r \). The real investment, therefore, benefits in relative terms from the higher wealth taxation of the default alternative. The present value of the investment project increases while the corresponding increase of the present value of wealth tax payments is not equally substantial. A lower discount rate reduces option values (see, for example, Merton 1973), which makes immediate investment more attractive. An increased project value and a reduced option value due to a higher \( \gamma \) both contribute to accelerated investment. As a tax policy consequence, broadening the wealth tax base by switching from a tax on special assets (\( \gamma = 0 \)) to a general wealth tax (\( \gamma = 1 \)) accelerates investment especially during periods of high interest rates and under moderate wealth tax rates. If high interest rates are an indicator for an economic boom, further acceleration of investment contributes to a procyclical tax policy and may not be desirable. Tax legislators may therefore consider narrowing the wealth tax base from a general wealth tax to a tax on particular assets in this situation.

However, with after-tax discount rates sufficiently close to zero, broadening the wealth tax base by increasing \( \gamma \) increases the critical investment threshold so that a counterintuitive wealth tax effect occurs.\(^{16}\) In these cases, increasing \( \gamma \) reduces the

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\(^{16}\) See Gries et al. (2012), who identify general conditions for neutral, normal, and paradoxical tax regimes if the differential between the drift parameter of the stochastic cash flow and the after-tax interest rate is sufficiently small.
discount rate such that the present value of wealth taxes increases not only relatively more than the present value of cash flows, but even overcompensates the reduction of the option value. This counterintuitive overall effect can be shown under HC as well as under FV and occurs for low pre-tax interest rates and high wealth tax rates. Hence, as investors currently face very low interest rates in the capital market, counterintuitive effects of broadening the wealth tax base are likely to occur. These effects tend to be even more distinctive for high cash flow uncertainty. If low interest rates indicate weak economic growth, broadening the wealth tax base delays investment, which again has a procyclical effect.

To illustrate scenarios that lead to intuitive and counterintuitive wealth tax effects we use numerical examples with the parameters $r = 0.04$, $\tilde{W}_H = 1$, $\alpha = 0$, $\sigma = 0.3$, $\tau_\pi = 0.25$, $\delta_\pi = 0.3$, $\delta_\omega \in \{0, 0.3\}$.\(^{17}\) Figure 1 displays the critical investment threshold under HC as a function of the parameter $\gamma$ for $\delta_\omega = 0.18\).

We observe intuitive effects with respect to $\gamma$ for $\tau_\omega = 0.01$ (dashed line, slightly decreasing), and counterintuitive effects for $\tau_\omega = 0.02$ (dotted line, increasing). As a reference case, the solid line indicates the critical threshold without wealth taxation ($\tau_\omega = 0$). For FV, the effects are similar and are therefore not displayed here.

For typical wealth tax rates (here: $\tau_\omega = 0.01$), the impact of wealth taxation on the after-tax discount rate is small. Consequently, variations of the fraction $\gamma$ of financial assets that is subject to wealth taxation do not affect the present value of cash flows and wealth tax payments as much as less typical higher wealth tax rates (here: $\tau_\omega = 0.02$). In the latter case, lower after-tax discount rates due to higher values of $\gamma$ increase the present value of wealth tax payments more than they increase the present value of cash flows and reduce the option value. For lower pre-tax interest rates

---

\(^{17}\) The after-tax discount rate $r_\pi$ is always strictly positive in the examples considered here.

\(^{18}\) The wealth tax value of the investment project is constant over time. Examples for a time-invariant tax value are investments in land or corporate stock. Studies that identify apparently paradoxical profit tax effects on the timing of risky investments in non-depreciable assets are, e.g., Schneider and Sureth (2010) and Gries et al. (2012).
Investment timing effects of wealth taxes under uncertainty…

\[(r < 0.04),\] counterintuitive reactions are even more likely to occur. For example, if \(r = 0.02\) a wealth tax rate of 0.6\% induces counterintuitive timing effects. It should be noted that the effects depend upon depreciation deductions for wealth tax purposes and can reverse for sufficiently high values of \(\delta_{\omega}.\)

Besides the broadness of the wealth tax base \(\gamma,\) the wealth tax rate \(\tau_{\omega}\) is an important driver of investment timing. Figure 1 shows that wealth taxation has a major impact on the level of the optimal investment threshold. Comparing the dashed and the dotted line to the case without wealth taxes, as represented by the solid line, reveals that wealth taxation can easily increase the critical threshold by 50\% or even 100\%. Obviously, neglecting wealth taxation can be harmful for investors.

To illustrate the forces at work, Fig. 2 displays the critical investment threshold as a function of the wealth tax rate \(\tau_{\omega}\) for \(\gamma = 1\) (solid lines) and \(\gamma = 0\) (dashed lines), and for different depreciation rates \(\delta_{\omega} = 0\) (LHS) and \(\delta_{\omega} = 0.3\) (RHS).

It is obvious to see that the depreciation rate for the project for wealth tax purposes is a crucial determinant of wealth tax effects. For low depreciation deductions (LHS), increased wealth tax rates delay investment, as was already observed in Fig. 1. For high depreciation deductions for wealth tax purposes (RHS), increased wealth tax rates accelerate investment. Positive wealth tax depreciation allowances are common for depreciable assets in most countries that levy a wealth tax. They often correspond to depreciation allowances used for profit tax purposes. For \(\delta_{\omega} = 0.3\) (RHS), we observe an intuitive tax effect for \(\gamma = 0\) and a counterintuitive tax effect for \(\gamma = 1.\) The latter effect arises because a higher wealth tax rate reduces the after-tax discount rate. This in turn increases the present value of cash flows more than the present value of wealth tax payments. In addition, the reduced discount rate reduces the option value, which also contributes to accelerated investment.

The opposing effects on the LHS and the RHS of Fig. 2 can be easily explained by the neutral PV of depreciation deductions for income tax purposes \(D_{\pi}^{HC}\) from (10). Since \(\partial D_{\pi}^{HC}/\partial \delta_{\omega} < 0,\) the actual depreciation PV, \(\delta_{\pi}/(r_{\pi} + \delta_{\pi})\), exceeds the neutral one for sufficiently high values of \(\delta_{\omega}\) and falls short of the neutral PV for low values of \(\delta_{\omega}\) such as \(\delta_{\omega} = 0.\)
The intuitive effects for a wealth tax-exempt default alternative ($\gamma = 0$) shown in both parts of Fig. 2 do not depend on the parameter setting, such as depreciation deductions.

**Proposition 4.4** For a wealth tax-exempt default alternative ($\gamma = 0$) increasing the wealth tax rate always delays investment.

**Proof**

\[
\frac{\partial \pi^H}{\partial \tau_w} \bigg|_{\gamma=0} = \frac{\beta - 1}{\beta} \cdot \frac{r - \alpha}{1 - \tau} \cdot \frac{\bar{W}_H}{r(1 - \tau) + \delta_w} > 0
\] (17)

\[
\frac{\partial \pi^F}{\partial \tau_w} \bigg|_{\gamma=0} = \frac{\beta - 1}{\beta} \cdot \frac{(r - \alpha)^2}{(r + \delta_w)(r - \delta_w)} \cdot \frac{\rho}{\rho} \left[ (1 - \tau) - \frac{\tau_w}{\rho} \left( \frac{r - \alpha}{r + \delta_w} \right) \right] > 0
\] (18)

As a consequence, the tax rate effects of a tax on special assets are easily predictable. If the wealth tax rate only affects the investment project, but not the option to invest or the default alternative, a tax rate increase always delays investment. Tax legislators should take this result into account when discussing tax rate variations of narrowly defined wealth taxes.

From the above analysis, we can derive three main tax policy conclusions: first, HC as a valuation method reduces the impact of wealth taxation compared to FV. This effect is due to the real option decision rule that triggers investment only when the expected PV of a project sufficiently exceeds its acquisition cost, and hence the wealth tax base under FV exceeds the one under HC. However, the tax legislator can reverse the effect of the valuation approach by choosing appropriate valuation parameters. Secondly, broadening the wealth tax base by raising $\gamma$ tends to produce procyclical effects if the interest rate is used as an indicator for the business cycle. This result, however, can be avoided by granting sufficiently high depreciation deductions for wealth tax purposes. In any case, a narrowly-defined tax base ($\gamma = 0$) increases the transparency of the emerging investment effects. Third, the investment timing effects of wealth tax rate variations crucially depend upon the depreciation rate for wealth tax purposes. If increasing the tax rate is supposed to induce harmful effects, i.e., investment is delayed (accelerated) too much, it is possible to reverse these effects by granting more (less) depreciation deductions $\delta_{\omega}$.

Variations of parameters that only affect the investment project, but not the option to invest or the default alternative, are the initial values for wealth tax purposes ($\bar{W}_H$ or $\rho$) and the depreciation rate $\delta_{\omega}$. Since the resulting effects are straightforward, the respective propositions and proofs are provided in Appendix C. All the results of this section do not change fundamentally if the profit tax is completely replaced by the wealth tax. Therefore, this case is not displayed here.
5 Conclusions and implications

Due to the current discussion on the (re-)introduction of wealth taxes in many jurisdictions, investors now need a set of decision rules for tax systems with both income and wealth taxes. We therefore analyze the impact of wealth taxation on investment timing decisions under uncertainty, irreversibility, and income and wealth taxation in a real options setting. We are the first to show that the impact of wealth taxation on investment timing in such a setting crucially depends upon the employed valuation method and the broadness and level of wealth taxation. We integrate different valuation methods for wealth tax purposes, distinguish between broadly and narrowly defined wealth taxes and vary the wealth tax rate to compute which wealth tax design is more or less likely to accelerate or delay investment.

Our main findings are threefold. First, historical cost valuation reduces the distortive timing effects of wealth taxation compared to fair value accounting. Second, broadening the wealth tax base tends to accelerate investment during high interest rates and to delay investment when there are low interest rates. This makes wealth taxes a threat to economic growth, especially in times of near-zero interest rates. This distortive wealth tax base effect, however, can be avoided by granting sufficiently high depreciation deductions for wealth tax purposes. Third, the investment timing effects created by wealth tax rate variations are very sensitive to the riskiness of the underlying investment. Moreover, investment timing effects crucially depend upon the depreciation rate for wealth tax purposes. A tax legislator who aims to encourage risk taking should introduce generous depreciation deductions.

Given that actual or currently planned tax systems are unlikely to meet our neutrality conditions and that most wealth tax reforms seem to incur highly project-specific investment behavior, investors are well-advised to take existing and expected wealth taxes into account in their decision calculus. Whether and how often an accelerating or a decelerating tax effect prevails is an empirical question and depends heavily upon the above-mentioned wealth tax parameters as well as the pre-tax interest rate and the expected cash flows of the investment project. Empirical tests are needed to learn more about the likelihood of the possible outcomes and the magnitude of the identified tax effects. Although investment timing decisions are notoriously hard to observe in practice, we can identify industries that could be good candidates for further investigation. Since real option theory is frequently applied in commodity-related industries, we expect observable results primarily in the oil, gas, mining, and forestry industry. As an example, the large fluctuations of oil prices over the last decade, in conjunction with recent wealth tax developments, could provide a framework for the analysis of investment timing decisions for (especially large) firms.

Finally, our study indicates that if a wealth tax is considered to be politically inevitable, possible harmful investment effects can be mitigated by choosing appropriate valuation methods and parameters. As our analysis emphasized that the investment effects are highly parameter-dependent, it is doubtful whether a tax legislator’s potential objectives regarding redistribution of wealth and tax revenues can be reached by wealth-related taxes.
Our analysis is subject to several limitations. Due to the assumption of equity financing, financial constraints and liquidity considerations are disregarded in the model. The revenue consequences of a wealth tax cannot be inferred from our results. This is because we take an individual rather than a macro perspective and set aside general equilibrium considerations. Moreover, our model focuses on purely domestic investment and disregards cross-border tax issues. Investigating aggregate effects of wealth taxation would require extensive assumptions beyond the scope of our model, such as a social discount rate or the usage of tax revenues, even if all investors were homogenous. Therefore, we delegate aggregate as well as distributive effects to future research. Compliance costs, which are often assumed substantial for wealth taxes, are disregarded in this paper. Our model is also limited to a perpetual option to invest for reasons of mathematical simplicity. Presuming a finite option lifetime and hence reduced option value we would expect less distinctive results. In contrast to our setting with risk neutral investors, investors are often considered risk averse. In principle, contingent claims analysis would allow us to abstract from risk aversion and use risk neutral valuation in real option approaches. Unfortunately, this approach requires the spanning property and a sophisticated Tax-CAPM that addresses the different risk profiles and taxation of the underlying assets and the options adequately. For our setting the integration of risk aversion still comprises a variety of unsolved theoretical caveats.\textsuperscript{19}

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\textsuperscript{19} See Niemann and Sureth (2004) who investigate neutral profit taxation under risk aversion.
Appendix A: Individual and corporate wealth taxes across the world

Wealth taxes in selected OECD and OECD key partner countries from 2005 to 2017, Sources: BMF (2017), Deloitte (2004–2017), EY (2017), IBFD (2017), KPMG (2004–2017), PwC (2004–2017). Wealth taxes on selected property, like taxes on vehicles, real estate, etc. are not included in this figure. Wealth tax discussions and reforms have been considered since 2005.

Appendix B: Proof of proposition 2.1 (critical investment thresholds)

Proof The project values were derived in (3) and (4). The next step in solving the investment problem requires the option value which will be derived by dynamic programming. Since the option does not entitle to depreciation allowances, is neither included in the wealth tax base, nor does it trigger any direct tax payments and therefore does not yield any cash flows (see Sect. 2), the only instantaneous benefit to the owner is the expected increase in value. The resulting equilibrium condition implies that the owner of the option receives an instantaneous return that equals the after-tax risk-free rate over a time interval of length $dt$:

$$E[dF_t] = r_t F_t dt.$$  \hfill (19)
Applying Itô’s lemma to the stochastic differential $dF_\tau$ and further transformation yields the ordinary differential equation\(^{20}\)

$$\frac{1}{2} \sigma^2 \pi^2 \frac{d^2 F_\tau}{d\pi^2} + \alpha \pi \frac{dF_\tau}{d\pi} - r_\tau F_\tau = 0$$ \hspace{1cm} (20)

with the solution

$$F_\tau(\pi) = A \pi^{\beta_\tau}, \quad \text{with} \quad \beta_\tau = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right)^2 + \frac{2r_\tau}{\sigma^2}} > 1,$$ \hspace{1cm} (21)

where $A > 0$ is a constant to be determined. From $A, \beta_\tau > 0$ it is obvious that $F_\tau(0) = 0$ holds. This condition implies that an option on a valueless underlying is itself valueless.

With this solution for the option value, two free boundary conditions are needed to find the critical investment threshold $\pi_0$ at which it is optimal to exercise the option immediately (see Dixit and Pindyck 1994, p. 141). The value matching condition requires that the project’s benefits, as defined by its expected present value, must equal its costs, which are given by acquisition costs and abandoned option value at the point of transition

$$V_\tau(\pi_0) - 1 = F_\tau(\pi_0).$$ \hspace{1cm} (22)

The smooth pasting condition requires the identity of marginal benefits and marginal costs at the critical threshold

$$\frac{dV_\tau(\pi_0)}{d\pi_0} = \frac{dF_\tau(\pi_0)}{d\pi_0}.$$ \hspace{1cm} (23)

The solution for $F_\tau$ from (21) as well as the project values from (3) and (4) are substituted into the value matching and smooth pasting conditions (22) and (23):

$$\text{HC:} \quad \left(1 - \frac{\tau_\pi}{r_\tau - \alpha}\right) \pi_0 + \frac{\tau_\pi \delta_\pi}{r_\tau + \delta_\pi} - \frac{\tau_\omega \overline{W}_{HC}}{r_\tau + \delta_\omega} = (A \pi_0)^{\beta_\tau},$$ \hspace{1cm} (24)

\(^{20}\) The time derivative vanishes due to the assumption of an infinite lifetime of the option to invest ($\partial F_\tau/\partial t = 0$).
Investment timing effects of wealth taxes under uncertainty…

\[
\frac{1 - \tau_x}{r_t - \alpha} = A \beta_t \pi_0^\beta - 1, \quad (25)
\]

\[
\text{FV: } \frac{(1 - \tau_x)\pi_0}{r_t - \alpha} + \frac{\tau_x \delta_x}{r_t + \delta_x} - \frac{\pi_0}{\rho} \frac{\tau_\omega}{r_t + \delta_\omega} - 1 = A \pi_0^\beta, \quad (26)
\]

\[
\frac{1 - \tau_x}{r_t - \alpha} - \frac{1}{\rho} \frac{\tau_\omega}{r_t + \delta_\omega} = A \beta_t \pi_0^\beta - 1. \quad (27)
\]

Dividing the value matching condition by the corresponding smooth pasting condition and further transformation yields the critical investment thresholds

\[
\pi_0^{HC} = \frac{\beta_t}{\beta_t - 1} \cdot \frac{r_t - \alpha}{1 - \tau_x} \left(1 - \tau_x \frac{\delta_x}{r_t + \delta_x} + \tau_\omega \frac{\overline{W}_{HC}}{r_t + \delta_\omega}\right). \quad (28)
\]

\[
\pi_0^{FV} = \frac{\beta_t}{\beta_t - 1} \cdot \frac{r_t - \alpha}{1 - \tau_x} - \frac{\tau_\omega}{\rho} \left(1 - \tau_x \frac{\delta_x}{r_t + \delta_x}\right). \quad (29)
\]

\[\square\]

Appendix C: Derivation of unambiguous results

**Proposition C.1** Increasing the initial tax value of the project \(\overline{W}_{HC}\) under historical cost accounting unambiguously increases the critical investment threshold.\(^{21}\)

**Proof**

\[
\frac{\partial \pi_0^{HC}}{\partial \overline{W}_{HC}} = \frac{\beta_t}{\beta_t - 1} \cdot \frac{r_t - \alpha}{1 - \tau_x} \cdot \frac{\tau_\omega}{r_t + \delta_\omega} > 0. \quad (30)
\]

\[\square\]

\(^{21}\) This partial derivative only makes sense under historical cost accounting. Under fair value accounting, the initial tax value \(\overline{W}_{FV}\) is a function of the cash flow \(\pi_0^\beta\).
Proposition C.2 Increasing the multiplier \( f(\rho) = 1/\rho \) under fair value accounting unambiguously increases the critical investment threshold.

\[ \frac{\partial \pi^{FV}_0}{\partial \rho} = -\frac{\beta_{\tau}}{b_{\tau} - 1} \cdot \frac{\tau_\omega (r_{\tau} - \alpha)^2 (r_{\tau} + \delta_\omega)}{\left[ \rho (1 - \tau_{\pi}) (r_{\tau} + \delta_\omega) - \tau_\omega (r_{\tau} - \alpha) \right]^2} \left( 1 - \frac{\tau_{\pi} \delta_{\pi}}{r_{\tau} + \delta_{\pi}} \right) < 0. \]

Because \( \frac{\partial f}{\partial \rho} = -\frac{1}{\rho^2} < 0 \) and
\[ \frac{\partial \pi^{FV}_0}{\partial \rho} = \frac{\partial f}{\partial \rho} \cdot \frac{\partial f}{\partial \rho} \]
\[ \Leftrightarrow \frac{\partial \pi^{FV}_0}{\partial f} \frac{\partial f}{\partial \rho} = \frac{\partial f}{\partial \rho} > 0. \]

(31)

Proposition C.3 Increasing the depreciation rate for wealth tax purposes \( \delta_\omega \) under historical cost accounting and fair value accounting unambiguously reduces the critical investment threshold.

\[ \frac{\partial \pi^{HC}_0}{\partial \delta_\omega} = -\frac{\beta_{\tau}}{b_{\tau} - 1} \cdot \frac{r_{\tau} - \alpha}{1 - \tau_{\pi}} \cdot \frac{\tau_\omega \overline{W}_{HC}}{(r_{\tau} + \delta_\omega)^2} < 0, \]

(32)

\[ \frac{\partial \pi^{FV}_0}{\partial \delta_\omega} = -\frac{\beta_{\tau}}{b_{\tau} - 1} \cdot \frac{\rho \tau_\omega (r_{\tau} - \alpha)^2}{\left[ \rho (1 - \tau_{\pi}) (r_{\tau} + \delta_\omega) - \tau_\omega (r_{\tau} - \alpha) \right]^2} \cdot \left( 1 - \frac{\tau_{\pi} \delta_{\pi}}{r_{\tau} + \delta_{\pi}} \right) < 0. \]

(33)

Appendix D: Algebraic signs of selected partial derivatives

To describe in more detail which conditions induce intuitive or counterintuitive tax effects, we compute the partial derivatives \( \partial \pi^{HC}_0 / \partial \tau_\omega \) and \( \partial \pi^{HC}_0 / \partial \gamma \) in some limiting cases.

The critical investment threshold for historical cost accounting is given by

\[ \pi^{HC}_0 = \frac{\beta_{\tau}}{b_{\tau} - 1} \cdot \frac{r_{\tau} - \alpha}{1 - \tau_{\pi}} \cdot \left( 1 - \tau_{\pi} \frac{\delta_{\pi}}{r_{\tau} + \delta_{\pi}} + \tau_\omega \frac{\overline{W}_{HC}}{r_{\tau} + \delta_\omega} \right). \]

(34)
To compute the partial derivatives with respect to \( \tau_\omega \) and \( \gamma \) we use the substitutions

\[
f = \frac{\beta_\tau}{\beta_\tau - 1},
\]

(35)

\[
g = \frac{r_\tau - \alpha}{1 - \tau_\pi},
\]

(36)

\[
h = 1 - \tau_\pi \frac{\delta_\pi}{r_\tau + \delta_\pi} + \tau_\omega \frac{\bar{W}_{HC}}{r_\tau + \delta_\omega},
\]

(37)

so that the critical investment threshold can be written as \( \pi_0^{HC} = f \cdot g \cdot h \). Consequently, we have

\[
\frac{\partial \pi_0^{HC}}{\partial \tau_\omega} = \frac{\partial f}{\partial \tau_\omega} \cdot g \cdot h + f \cdot \frac{\partial g}{\partial \tau_\omega} \cdot h + f \cdot g \cdot \frac{\partial h}{\partial \tau_\omega},
\]

(38)

with

\[
\frac{\partial f}{\partial \tau_\omega} = \frac{\gamma}{\sigma^2 (\beta_\tau - 1)^2 \left( \beta_\tau - \frac{1}{2} \right) + \frac{\alpha}{\sigma^2}} \geq 0,
\]

(39)

\[
\frac{\partial g}{\partial \tau_\omega} = \frac{-\gamma}{1 - \tau_\pi} \leq 0,
\]

(40)

\[
\frac{\partial h}{\partial \tau_\omega} = \frac{\bar{W}_{HC} \left[ r(1 - \tau_\tau) + \delta_\omega \right]}{(r_\tau + \delta_\omega)^2} - \frac{\gamma \tau_\pi \delta_\pi}{(r_\tau + \delta_\omega)^2} \gtrless 0.
\]

(41)

Substitution and further transformation yields

\[
\frac{\partial \pi_0^{HC}}{\partial \tau_\omega} = \left( 1 - \tau_\pi \delta_\pi \right) r_\tau + \bar{W}_{HC} \frac{\tau_\omega \delta_\omega}{r_\tau + \delta_\omega} \right) \left[ \begin{array}{c}
\frac{r_\tau - \alpha}{\sigma^2 (\beta_\tau - 1)^2 \left( \beta_\tau - \frac{1}{2} \right) + \frac{\alpha}{\sigma^2}} \\
\beta_\tau - 1
\end{array} \right] \\
\frac{\beta_\tau - 1}{\beta_\tau - 1} \frac{r_\tau - \alpha}{1 - \tau_\pi} \left[ \begin{array}{c}
\frac{\bar{W}_{HC} \left[ r(1 - \tau_\tau) + \delta_\omega \right]}{(r_\tau + \delta_\omega)^2} \\
\frac{\gamma \tau_\pi \delta_\pi}{(r_\tau + \delta_\omega)^2}
\end{array} \right] \geq 0.
\]

(42)
Although this expression is too complicated for a general discussion, it is possible to derive the algebraic sign of the partial derivative for some limiting cases.

**Proposition D.1** In the limiting case of no uncertainty ($\sigma \to 0$), the effect of increasing the capital tax rate is indeterminate.

**Proof**

\[
\lim_{\sigma \to 0} \frac{\partial \pi^{HC}_0}{\partial \tau_{\omega}} = \frac{1}{1 - \tau^*} \left( -\gamma - \frac{W^{HC} r_{\omega} \tau_{\omega}}{r^* + \delta^*} + \frac{\gamma \tau_{\omega} \delta^*}{r^* + \delta^*} \right) + r - \alpha \left[ \frac{W^{HC} [r (1 - \tau) + \delta_{\omega}]}{(r^* + \delta_{\omega})^2} - \frac{\gamma \tau_{\omega} \delta^*}{(r^* + \delta^*)^2} \right]
\]

(43)

\[
= g \begin{cases} 
\frac{\partial h}{\partial \tau_{\omega}} & > 0 \\
\frac{\gamma \cdot h}{r^* - \alpha} & \geq 0 \\
\geq 0 & \geq 0 
\end{cases}.
\]

\]

**Proposition D.2** In the limiting case of uncertainty approaching infinity ($\sigma \to \infty$), the effect of increasing the capital tax rate is indeterminate.

**Proof**

\[
\lim_{\sigma \to \infty} \frac{\partial \pi^{HC}_0}{\partial \tau_{\omega}} = \lim_{\sigma \to \infty} \left[ h \cdot \left( \frac{\partial f}{\partial \tau_{\omega}} \cdot g + f \cdot \frac{\partial g}{\partial \tau_{\omega}} \right) + f \cdot g \cdot \frac{\partial h}{\partial \tau_{\omega}} \right]
\]

(44)

\[
= h \cdot \lim_{\sigma \to \infty} \left( \frac{\partial f}{\partial \tau_{\omega}} \cdot g + f \cdot \frac{\partial g}{\partial \tau_{\omega}} \right) + g \cdot \frac{\partial h}{\partial \tau_{\omega}} \cdot \lim_{\sigma \to \infty} f
\]

\[
= - \frac{2\gamma}{1 - \tau^*} \cdot h + g \cdot \frac{\partial h}{\partial \tau_{\omega}} \cdot \infty
\]

\[
= \infty \cdot \text{sgn} \left( \frac{\partial h}{\partial \tau_{\omega}} \right).
\]

The results of these extreme cases indicate that the impact of increasing the wealth tax rate largely depends upon the valuation of the project as long as the default alternative is (at least partially, $0 < \gamma \leq 1$) subject to wealth taxation. The degree of uncertainty is crucial for the likelihood of counterintuitive investor reactions.

Considering the impact of wealth taxation for the default alternative, we have a very similar partial derivative

\[
\frac{\partial \pi^{HC}_0}{\partial \gamma} = \frac{\partial f}{\partial \gamma} \cdot g + f \cdot \frac{\partial g}{\partial \gamma} \cdot h + f \cdot g \cdot \frac{\partial h}{\partial \gamma},
\]

(45)
with
\[
\frac{\partial f}{\partial \gamma} = \frac{\tau_\omega}{\sigma^2 (\beta_\tau - 1)^2 \left( \beta_\tau - \frac{1}{2} + \frac{a}{\sigma^2} \right)} \geq 0, 
\]
(46)

\[
\frac{\partial g}{\partial \gamma} = -\frac{\tau_\omega}{1 - \tau_\pi} \leq 0, 
\]
(47)

\[
\frac{\partial h}{\partial \gamma} = \frac{\tau_\omega^2 \overline{W}_{HC}}{(r_\tau + \delta_\omega)^2} - \frac{\tau_\omega \tau_\pi \delta_\pi}{(r_\tau + \delta_\pi)^2} \geq 0. 
\]
(48)

Substitution and further transformation yields

\[
\frac{\partial \pi_0^{HC}}{\partial \gamma} = \left( 1 - \frac{\tau_\pi \delta_\pi}{r_\tau + \delta_\pi} + \frac{\tau_\omega \overline{W}_{HC}}{r_\tau + \delta_\omega} \right) \cdot \frac{\tau_\omega}{1 - \tau_\pi} \begin{bmatrix}
\frac{r_\tau - \alpha}{\sigma^2 (\beta_\tau - 1)^2 \left( \beta_\tau - \frac{1}{2} + \frac{a}{\sigma^2} \right)} & -\frac{\beta_\tau}{\beta_\tau - 1} \\
\beta_\tau - 1 & \frac{r_\tau - \alpha}{\sigma^2 (\beta_\tau - 1)^2 \left( \beta_\tau - \frac{1}{2} + \frac{a}{\sigma^2} \right)} \end{bmatrix} \\
\frac{\tau_\omega \overline{W}_{HC}}{(r_\tau + \delta_\omega)^2} & -\frac{\tau_\omega \tau_\pi \delta_\pi}{(r_\tau + \delta_\pi)^2} \\
\beta_\tau - 1 & \frac{r_\tau - \alpha}{\sigma^2 (\beta_\tau - 1)^2 \left( \beta_\tau - \frac{1}{2} + \frac{a}{\sigma^2} \right)} \\
\beta_\tau - 1 & \frac{\tau_\pi \delta_\pi}{(r_\tau + \delta_\pi)^2} \end{bmatrix}.
\]
(49)

**Proposition D.3** In the limiting case of pre-tax interest rates approaching infinity (\( r \to \infty \)), increasing the wealth-taxable fraction of the default alternative always reduces the critical investment threshold.

**Proof**

\[
\lim_{r \to \infty} \frac{\partial \pi_0^{HC}}{\partial \gamma} = -\frac{\tau_\omega}{1 - \tau_\pi} < 0. 
\]
(50)

\( \square \)

**Proposition D.4** In the limiting case of no uncertainty (\( \sigma \to 0 \)), the effect of increasing the wealth-taxable fraction of the default alternative is indeterminate.
Proof
\[
\lim_{\sigma \to 0} \frac{\partial \pi_0^{HC}}{\partial \gamma} = \frac{-\tau_\omega}{1 - \tau_\pi} \left( 1 + \frac{W_{HC} \tau_\omega}{r_\tau + \delta_\omega} + \frac{\tau_\pi \delta_\pi}{r_\tau + \delta_\pi} \right) + \frac{\tau_\omega (r_\tau - \alpha)}{1 - \tau_\pi} \left[ \frac{\tau_\omega W_{HC}}{(r_\tau + \delta_\omega)^2} - \frac{\tau_\pi \delta_\pi}{(r_\tau + \delta_\pi)^2} \right]
\]
\[
= \frac{-\tau_\omega}{1 - \tau_\pi} \left[ h - (r_\tau - \alpha) \frac{\partial h}{\partial \gamma} \right].
\] (51)

Proposition D.5 In the limiting case of uncertainty approaching infinity (\(\sigma \to \infty\)), the effect of increasing the wealth-taxable fraction of the default alternative is indeterminate.

Proof
\[
\lim_{\sigma \to \infty} \frac{\partial \pi_0^{HC}}{\partial \gamma} = \lim_{\sigma \to \infty} \left[ h \cdot \left( \frac{\partial f}{\partial \gamma} \cdot g + f \cdot \frac{\partial g}{\partial \gamma} \right) + f \cdot g \cdot \frac{\partial h}{\partial \gamma} \right]
\]
\[
= h \cdot \lim_{\sigma \to \infty} \left( \frac{\partial f}{\partial \gamma} \cdot g + f \cdot \frac{\partial g}{\partial \gamma} \right) + g \cdot \frac{\partial h}{\partial \gamma} \cdot \lim_{\sigma \to \infty} f
\]
\[
= - \frac{2 \tau_\omega}{1 - \tau_\pi} \cdot h + g \cdot \frac{\partial h}{\partial \gamma} \cdot \infty
\]
\[
= \infty \cdot \text{sgn} \left[ \frac{\partial h}{\partial \gamma} \right].
\] (52)

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