Dividend and corporate income taxation with present-biased consumers

Minwook Kang
Korea University

Lei Sandy Ye
Acumen, LLC

March 20, 2023

Abstract

Debates on the double taxation of dividends and corporate income have been long-standing. If double taxation were to be avoided, which type of tax policy would be more ideal? Conventional corporate theory based on microeconomic approaches does not yield a definitive answer, as either policy would distort firm investment and decrease firm value. Distinct from previous models, this paper addresses the double taxation issue in a macroeconomic context under a Laibson-type hyperbolic discounting model. In particular, this paper shows that in the hyperbolic economy, dividend taxes can improve consumer welfare, even though they decrease firm value. On the other hand, corporate income taxes negatively impact both consumers and firms. We also extend this result in an infinite-period steady-state model and show quantitative implications.

Keywords: Double taxation; Dividend tax; Corporate income tax; Present-biased preferences; Hyperbolic discounting

JEL codes: H25, G38, E22.

The authors appreciate comments and suggestions from an associate editor and an anonymous referee. We thank Kyoo-Won Yang for the great research assistance. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of Acumen, LLC. All errors are our own.

Contact: Kang - kangmw@korea.ac.kr.

1. Introduction

When dividend taxes are imposed along with corporate income taxes, a double taxation of corporate profits can arise and this has been a source of long-standing debate. Under double taxation, two types of taxes are levied on the same corporate income source for shareholders. Policymakers often face a choice on the relative weight placed on these two tax policies. In the United States, tax reforms in the past twenty years have adjusted both the dividend and corporate income tax rates. For example, the dividend tax was reduced to 15 percent in 2003, while nearly 15 years later, the corporate profits tax was reduced to an effective rate of 21 percent.[1] In other countries, policies have sought to integrate these two taxes, such as corporate tax deductions of dividends. These varied policies reflect the lack of consensus on the relative costs and benefits of these two tax policies.

If double taxation were to be avoided, which tax policy would be ideal from a policy standpoint? Another important question is can corporate taxes benefit the macroeconomy as a whole even though they decrease firm value? Most previous models on this issue are restricted to the pure corporate setting. Conclusions about corporate tax choices can vary based on the choice of market friction in the microeconomic context. For example, Chetty and Saez (2010)'s model is a two-period corporate agency setting where the manager can invest in unproductive projects (i.e., "pet" project), which would increase the manager's, but not the shareholder's utility. They show that corporate income taxes can help curb investment in "pet" projects by increasing shareholders' wealth. On the other hand, Kang and Ye (2019) show that dividend taxes can improve firm value if the manager has more short-term oriented preferences than the owner.

Both Chetty and Saez (2010) and Kang and Ye (2019) are modeled based on agency problems, as commonly assumed in the finance and economics literature. In the presence of asymmetric information between managers and shareholders, managers can make myopic decisions even with a rational choice framework (e.g., Edman 2009). However, this paper diverges from the finance literature in the following two ways. First, the source of myopic decisions in this paper is cognitive bias rather than asymmetric information. Second, we consider the corporate taxation problem from a macroeconomic perspective with present biased consumers, which helps examine whether reduced firm value from

[1]The corporate finance literature on the linkage between dividend tax and corporate decisions is diverse. Examples assessing corporate payouts include Brown, Liang, and Weisbenner (2007), Brav et al. (2008), and Hanlon and Hoopes (2014). Others study the impact on stock prices and firms' returns, such as Dhaliwal, Li, and Trezevant (2003) and Amromin, Harrison, and Sharpe (2008).

corporate taxes necessarily implies a negative effect on the economy as a whole.[2] In the macroeconomic context, the owners of firms are consumers. Thus, if they were better off from a corporate tax policy, we can say that the policy is welfare-improving even though firm value decreases.

To assess overall welfare impact from corporate taxes, we use a non-exponential discounting model, which better explains how consumers' present bias affects financial markets. This approach is supported by vast experimental and empirical evidence that individuals are impatient in the short run relative to their long run preferences.[3] Specifically, Richard Thaler's (1981) survey evidence shows that people would be indifferent between receiving \$15 immediately or \$30 after 3 months, \$60 after 1 year, or \$100 after 3 years. These indifferences indicate that people are present biased, as annual discount rates decrease from 277% to 139% to 63% with longer delays.[4] These indifferences cannot be explained by conventional exponential discounting.

Among non-exponential discounting models, our paper is specifically grounded on the quasi-hyperbolic discounting model of Laibson (1997). In light of evidence on present-biased behavior, Laibson (1997) proposed this model, which assumes that discount factors over time are changing non-exponentially. Specifically, the discount factors between now to 1, 2, and 3 years later are $\beta\delta, \beta\delta^2$, and $\beta\delta^3$, respectively. If $\beta < 1$, this approach can generate non-constant discount rates. Specifically, in Thaler's survey example, letting $\beta = 0.723$ and $\delta = 0.578$, we can derive 139% and 63% as annual discount rates for \$60 after 1 year, or \$100 after 3 years, respectively.[5] Laibson (1997) incorporates this quasi-hyperbolic discounting model (i.e., the β-δ model) into the intertemporal utility model, which is still actively used in various research areas including the finance literature (e.g., Grenadier and Wang 2007 and Kuchler and Pagel 2021).

Present-biased consumers (whose discount rates decline over time) inevitably have

[2] There is limited evidence that a corporation makes decisions based on present-biased preferences, but there is much evidence that consumers are present-biased. As Grenadier and Wang (2007) suggested, firms are less likely to be present-biased, as professional managers might help mitigate time inconsistency from firms' decisions. DellaVigna and Malmendier (2004) also assumed that consumers are time-inconsistent, but firms are rational.

[3] See Thaler (1981), Loewenstein and Prelec (1992), and Frederick, Loewenstein, and O'Donoghue (2002) for discussions on present-biased preferences. Based on this evidence, Strotz (1956), Phelps and Pollak (1968), and Laibson (1997) constructed intertemporal consumption-savings decision models based on present-biased preferences.

[4] This type of present bias is also well-observed in consumers' credit market data, which shows that many consumers fail to stick to their planned debt payments due to present bias (see Kuchler and Pagel, 2021).

[5] Specifically, the values of β and δ can be derived from the following two equations: $\beta\delta = (1+1.39)^{-1}$ and $\beta\delta^3 = (1+0.63)^{-3}$. We ignore the discount rate for 3 months because here we defined β and δ in the annual base.

time-inconsistent consumption-savings decision problems. Based on the β-δ model, a current self would make a decision of savings (whose return will be realized in 1 year) based on the annual discount factor of $\beta\delta$ ($\beta\delta = 0.418$ in the above example). At the same time, the current self wants the future self (1 year later) to make the savings decision based on the discount factor of δ ($\delta = 0.578$ in the above example) instead of $\beta\delta$.[6] However, when the future arrives, the future self's 1-year discount factor would be $\beta\delta$ rather than δ. From the perspective of the current self, the future self will undersave due to the future self's low level of discount factor (that is $\beta\delta$). This disjunction between current and future selves' discount factors results in undersavings problems.

The natural next question is how outside authorities such as governments can help amend this undersaving problem. One option is to allow government market intervention through various tax policies. Considerable research suggests a role for tax policies that induce consumers to save more. A main policy tool is the savings subsidy policy (i.e., a capital subsidy or interest subsidy), which decreases the cost of savings, thus inducing consumers to increase equilibrium savings (see Laibson 1996, Krusell, Kuruşçu and Smith, 2010, and Pavoni and Yazici, 2017).[7] Even though a large literature investigates tax policy on consumers, these papers have not investigated the impact of corporate taxes in a hyperbolic economy.

In a production economy, government corporate tax policy affects corporate investment decisions, resulting in the change of equilibrium interest rates. This paper investigates a corporate tax policy that helps amend the underinvestment problem resulting from present-biased consumers. To model corporate tax policy in a macroeconomy, this paper incorporates a corporation's dividend-investment decision model into a representative macroeconomics model, similar to Kang and Ye (2021) and Kang (2022). The firm maximizes the present value of dividend payouts and decides on the investment amount and dividend payout. Even if the firm behaves rationally, the firm will not hold enough capital stock if present-biased consumers save less through the stock and bond markets. These consumers' undersavings through the capital markets will result in firms being short on cash, which causes an underinvestment problem.

The main conclusion of this paper is that both corporate income taxes and dividend taxes decrease firm value, but dividend taxes can improve consumer welfare. Specifically,

[6] In the numerical analysis in this paper, we will use $\beta = 0.7$ and $\delta = 0.981$, which are commonly-used values in macroeconomic models.

[7] The most well-known policy to resolve the undersaving problem under hyperbolic discounting would be a saving subsidy policy as proposed by Laibson (1996). That savings subsidy policy is a supply-side policy that increases the capital supply from consumers. The policy proposed in this paper is, in contrast, a demand-side policy that increases firms' demand for capital.

this paper shows that there is always a Pareto-improving dividend tax policy under a revenue-neutral regime. To show this main result, we assume that the collected dividend tax is distributed as lump-sum subsidies to consumers or corporations, resulting in no net change in government revenue. The main difficulty in designing a welfare-improving tax-subsidy policy under hyperbolic discounting is that a one-period tax policy decreases that period's intertemporal utility. This is because the consumer rationally maximizes intertemporal utility in each period, which is viewed as biased from the perspective of other periods but not from that of the current period. However, we show that the policy in one period can improve the other periods' intertemporal utilities, so the combination of all periods' policies can Pareto-improve the equilibrium allocations.

The following is a simple explanation for how a dividend tax can boost consumers' welfare. Dividend taxes increase the firm's cost of dividend payout and thereby decrease the relative cost of investment. Therefore, the dividend tax increases the firm's demand, which eventually induces consumers to save more through the capital market. On the other hand, corporate income taxes decrease firm's demand, which leads to the under-saving problem and lowers welfare. In the case where the government use both corporate income and dividend taxes, we show that the dividend tax rate should be higher than the corporate income tax rate to achieve Pareto-improvement. On the other hand, if the consumer is rational (i.e., $\beta = 1$), the model is the same as the conventional macroeconomic model. Therefore, any government intervention decreases welfare, which implies that the optimal dividend and income tax should both be zero. Specifically, any dividend tax results in overinvestment if the consumer is rational.

We extend our results to an infinite-period model with logarithm utility. With this framework, we show that decreasing dividend tax rates over time can improve welfare even with the presence of corporate income tax. The current dividend tax decreases the relative cost of the current-period investment. However, the marginal benefit of current investment, i.e., the future marginal product of capital, would be decreased by a future dividend tax. In the finite-period model, the dividend tax in the last period does not affect consumers' decisions, which implies that the dividend tax policy does not decrease the marginal product of capital in the last period. Therefore, in the finite-period model, positive dividend taxes could be necessary and sufficient for a Pareto-improvement. However, in the infinite-period model, to achieve Pareto-improvement, the dividend tax policy should be designed in a way where the downward effect on marginal cost of investment outweighs the upward effect on marginal benefit of investment in all periods, which implies the current dividend tax rate should be higher than the subsequent periods' dividend tax rates. We calculate the optimal degree of decreasing dividend tax rate in the steady-state model and also compute the welfare gain from the dividend tax policies using the model in Kang and Ye (2021).

The rest of the paper is organized as follows. Section 2 introduces a macroeconomic model in which the representative firm makes dividend-investment decisions. Section 3 shows that the dividend tax policy can Pareto-improve the equilibrium allocations in the three-period model. Section 4 shows the negative effect from corporate income taxes under the hyperbolic economy. Section 5 shows that the dividend tax rate should be greater than the corporate income tax rate for achieving Pareto-improvement. Section 6 shows the steady-state analysis. Section 7 concludes. In Appendix A, the paper presents a leading example to help interpret the main results in this paper. All the proofs of propositions and lemmas are in the other Appendices.

2. The model

This section introduces a three-period model in which a representative consumer maximizes hyperbolically-discounted intertemporal utilities and a representative firm maximizes the present value of dividend payouts. To incorporate time-inconsistency into the macroeconomic model, we need at least three periods.

2.1. A representative firm

We define a representative firm's production function in period t as $A_tF(K_t, N_t)$, where A_t, K_t, and N_t represent the period-t total factor productivity, aggregate capital, and aggregate labor, respectively. Function $F(K_t, N_t)$ satisfies the Inada conditions and exhibits constant returns to scale. We define the per-worker production function as $f_t(k_t) = A_tF(K_t, N_t)/N_t$, where k_t $(= K_t/N_t)$ is the per-capita capital in period t. Assume that there exists a continuum of individual agents indexed by the unit interval. Individual decision and state variables are represented by an i index. Labor is assumed to be supplied inelastically, so $N_t = \int_0^1 N_t(i)di = 1$.

In each period, the firm makes decisions on dividend payout and investment. If the firm invests I_t amount of capital goods in period t, capital in period $t+1$ would be $K_{t+1} = K_t(1-d) + I_t$, where $d \in (0, 1)$ represents the capital depreciation rate. In period 0, the firm is endowed with K_0 units of capital and indebted with b_{-1} units of bonds.

Denote v_t as the dividend payout in period t; then the dividend payout in periods 0, 1, 2 would be

$$v_0 = A_0F(K_0, N_0) - I_0 - w_0N_0 - R_0b_{-1} + b_0, \tag{1}$$

$$v_1 = A_1F(K_1, N_1) - I_1 - w_1N_1 - R_1b_0 + b_1, \tag{2}$$

$$v_2 = A_2F(K_2, N_2) - w_2N_2 - R_2b_1 + (1 - d)(1 - \chi)K_2 \tag{3}$$

where

v_t : dividend payout,	w_t : real wage,
b_t : corporate bond issuance,	R_t : real gross interest rate,
I_t : investment,	χ : capital liquidation cost.

In periods 0 and 1, the firm makes decision on dividends and investments as shown in *Eqs.* (1) and (2). In this paper, we assume that the firm issues bonds but not shares of stock. However, including the stock market does not change the main result of this paper because in a complete market, the effective value of stock and bonds should be the same.

To ensure that the firm makes positive investment in each period (so the firm has no incentive to liquidate the capital), we assume that there is sufficient technological improvement such that $A_0 < A_1 < A_2$. In period 2, the last period, the firm liquidates all the capital with a proportional liquidation cost, χ, as shown in *Eq.* (3). The firm maximizes the present value of dividend payouts (i.e., firm value). The present value of dividend payouts are $v_0 + v_1/R_1 + v_2/(R_1R_2)$ in period 0, $v_1 + v_2/R_2$ in period 1, and v_2 in period 2, respectively.

The period-2 firm maximizes the present value of dividend payout:

$$\max_{N_2} v_2. \tag{4}$$

Given the capital level (K_2), the firm makes decisions based on its labor choice, so the first-order condition from the maximization problem of *Eq.* (4) is

$$w_2 = A_2F_2(K_2, N_2).$$

The period-1 firm maximizes its present value of dividend payout:

$$\max_{N_1, I_1, b_1} v_1 + v_2/R_2. \tag{5}$$

The first-order conditions in terms of labor and investment, respectively, from the period-1 maximization problem of *Eq.* (5) are

$$w_1 = A_1 F_2(K_1, N_1) \tag{6}$$

and

$$R_2 = A_2 F_1(K_2, N_2) + (1-d)(1-\chi). \tag{7}$$

The supply for corporate bonds (b_t) is perfectly inelastic in the maximization problem of *Eq.* (5), so the equilibrium quantity of bonds is determined by their consumer demand.

The firm's maximization problem in period 0 is

$$\max_{N_0, I_0, b_0} v_0 + v_1/R_1 + v_2/(R_1 R_2). \tag{8}$$

The first-order conditions from the period-0 maximization problem of *Eq.* (8) are

$$w_0 = A_0 F_2(K_0, N_0), \tag{9}$$

and

$$R_1 = A_1 F_1(K_1, N_1) + (1-d)\frac{A_2 F_1(K_2, N_2) + (1-d)(1-\chi)}{R_2}. \tag{10}$$

From *Eq.* (7) and (10), we can derive the firm's demand for period-0 investment:

$$R_1 = A_1 F_1(K_1, N_1) + (1-d). \tag{11}$$

2.2. A representative consumer

A representative consumer lives in three periods, $t = 0, 1, 2$. The consumer's period utility $u(c)$ is strictly increasing, strictly concave, twice continuously differentiable and $\lim_{c \to 0} u'(c) = \infty$, where c is a perishable consumption good. We assume that the representative consumer owns the firm and is endowed with b_{-1} units of corporate bonds in period 0. The consumer is endowed with one unit of labor good, which has an inelastic supply. Thus, the consumer's resource constraints are

$$c_0 + b_0 = w_0 + v_0 + R_0 b_{-1}, \tag{12}$$

$$c_1 + b_1 = w_1 + v_1 + R_1 b_0, \tag{13}$$

and

$$c_2 = w_2 + v_2 + R_2 b_1, \tag{14}$$

in periods 0, 1 and 2, where b_t, w_t, and v_t are the amount of bond holding, real wage, and the dividend income (i.e., dividend payout), respectively, in period t.[8]

The consumer's intertemporal utilities in the three periods, $U^{(0)}, U^{(1)}$, and $U^{(2)}$ are

$$U^{(0)}(c_0, c_1, c_2) = u(c_0) + \beta \left(\delta u(c_1) + \delta^2 u(c_2)\right),$$

$$U^{(1)}(c_1, c_2) = u(c_1) + \beta\delta u(c_2),$$

and

$$U^{(2)}(c_2) = u(c_2),$$

where $\delta \in (0,1)$ is a long-run discounting factor and $\beta \in (0,1)$ is a hyperbolic discounting factor. If $\beta = 1$, the consumer's preference follows exponential discounting and thus would be a time-consistent decision maker. If $\beta < 1$, the consumer follows quasi-hyperbolic discounting and thus would be time-inconsistent.

The consumer perfectly forecasts future market prices, labor income and dividend income. She also knows her future preferences (sophisticated consumer). Therefore, we can solve the maximization problems through backward induction. The period-2 self consumes all her financial and labor income, so the period-2 intertemporal utility is

$$U^{(2)}(c_2) = u(w_2 + v_2 + R_2 b_1).$$

Given $(R_t, w_t, v_t)_{t=1}^2$, the period-1 self solves the following maximization problem, conditional on b_0 :

$$\max_{b_1|b_0} U^{(1)} \left(w_1 + v_1 + R_1 b_0 - b_1, w_2 + v_2 + R_2 b_1\right). \tag{15}$$

From the maximization problem of *Eq.* (15), we implicitly derive b_1 as a function of b_0, conditional on $(R_t, w_t, v_t)_{t=1}^2$, denoted as $\bar{b}_1(b_0)$. Given the saving response function $\bar{b}_1(b_0)$ and $(R_t, w_t, v_t)_{t=0}^2$, the consumer chooses b_0 to maximize $U^{(0)}$:

$$\max_{b_0} U^{(0)} \begin{pmatrix} w_0 + v_0 + R_0 b_{-1} - b_0, w_1 + v_1 + R_1 b_0 - \bar{b}_1(b_0), \\ w_2 + v_2 + R_2 \bar{b}_1(b_0) \end{pmatrix}. \tag{16}$$

The consumer's optimal choice of savings can be characterized as a subgame perfect

[8] In *Eq.* (12), the value of R_0 does not affect the consumer's financial income (i.e., $v_1 + R_0 b_{-1}$), because higher R_0 decreases the firm's liability along with the consumer's dividend income, v_1.

Nash equilibrium, $\left(b_0^*, \bar{b}_1(b_0)\right)$, such that $\bar{b}_1(b_0)$ solves the period-1 maximization problem of *Eq.* (15), conditional on b_0; and b_0^* solves the period-0 maximization problem of *Eq.* (16).

2.3. The equilibrium

The equilibrium is characterized by the consumer's maximization problems in *Eqs.* (15) and (16), given $\{(R_t, w_t, v_t)_{t=0}^2, b_{-1}\}$; the firm's maximization problems in *Eqs.* (4), (5), and (8) given $\{(R_t, w_t)_{t=0}^2, b_{-1}\}$; and the labor as well as commodity market clearing conditions. In equilibrium, the gross interest rate, real wages, and dividends are given by

$$R_1 = f_1'(k_1) + (1-d), \tag{17}$$

$$R_2 = f_2'(k_2) + (1-d)(1-\chi), \tag{18}$$

$$w_t = f_t(k_t) - k_t f_t'(k_t) \text{ for all } \; t = 0, 1, 2, \tag{19}$$

and

$$v_t = k_t f_t'(k_t) - I_t - R_t b_{t-1} + b_t \text{ for all } \; t = 0, 1, 2. \tag{20}$$

where $f_t(k_t) = A_t F(K_t, N_t)$, $I_2 = 0$, and $b_2 = 0$.

From the firm and consumer's budget constraint in *Eqs.* (1-3) and (12-14), the commodity market clearing condition is reduced to

$$c_t = f_t(k_t) - I_t. \tag{21}$$

The bond market clearing condition is satisfied because we use the same symbol (b_t) for both consumer savings and the firm's bonds. We have the following labor market condition:

$$\textstyle\int_0^1 N_t(i)di = 1 = N_t, \text{ for all } \; t = 0, 1, 2.$$

2.4. Undersavings problems

It is a well-known result that present-biased consumers undersave, which means that increasing savings in equilibrium can improve their welfare (see Phelps and Pollak 1968; Goldman 1978; Laibson 1996). In a general-equilibrium model, this undersaving problem results in an underinvestment problem, which means that the economy does not have sufficient capital stock to optimize welfare. This section addresses this undersaving/underinvestment problem in the three-period model. Using the commodity market clearing conditions of *Eq.* (21) and $k_{t+1} = I_t + (1-d)k_t$, the equilibrium is characterized by two capital levels, i.e., (k_1, k_2). Thus, in equilibrium, the intertemporal utilities can be characterized as

$$\overline{U}^{(0)}(k_1,k_2) = U^{(0)}(f_0(k_0)+(1-d)k_0-k_1, f_1(k_1)+(1-d)k_1-k_2, f_2(k_2)+(1-d)(1-\chi)k_2),$$

$$\overline{U}^{(1)}(k_1,k_2) = U^{(1)}(f_1(k_1)+(1-d)k_1-k_2, f_2(k_2)+(1-d)(1-\chi)k_2)$$

and

$$\overline{U}^{(2)}(k_1,k_2) = U^{(2)}(f_2(k_2)+(1-d)(1-\chi)k_2),$$

where $\overline{U}^{(0)}(k_1,k_2)$, $\overline{U}^{(1)}(k_1,k_2)$ and $\overline{U}^{(2)}(k_1,k_2)$ are the intertemporal utilities in terms of (k_1, k_2).

Figure 1 describes the equilibrium capital levels (k_1^*, k_2^*) without any government intervention in an example with $f_i(k) = 10\sqrt{k}$ for i=0,1,2, $u(c) = \ln c$, $\delta = 1, \beta = 1/2, d = 100\%$, and $k_0 = 10$. As shown in Figure 1, the indifference curve of period-0 utility, $\overline{U}^{(0)}(k_1,k_2)$, passing through the equilibrium capital level has a circular shape, while the indifference curve of period-1 utility, $\overline{U}^{(1)}(k_1,k_2)$, has a slanted parabolic shape. The Pareto-superior region is the overlapping area between the two indifference curves, such that intertemporal utility values (i.e., $U^{(0)}, U^{(1)}$, and $U^{(2)}$) associated with any capital level inside this region are higher than those associated with the equilibrium capital level. The Pareto-superior region is located North-East of the equilibrium point, indicating an underinvestment problem for the economy.[9] For detailed proof of the existence of the underinvestment problem with general utility/production functions, see Appendix E.

In Figure 1, the capital response function $\overline{k}_2(k_1)$ represents the equilibrium capital in period 2 (k_2), given period-1 capital level k_1. The capital response function $\overline{k}_2(k_1)$ is different from the savings response function $\overline{b}_1(b_0)$, but the first derivatives of the two functions are the same, i.e., $\overline{k}_2'(k_1) = \overline{b}_1'(b_0)$.

3. Dividend tax policy

In the previous section, we introduced a general equilibrium model where the firm makes dividend-investment decisions and showed that the economy would experience an underinvestment problem without any government intervention. This section introduces Pareto-improving dividend tax policies.

[9] As β approaches 1 (i.e., the consumer becomes more time consistent), the Pareto-superior area shrinks and converges to the equilibrium point.

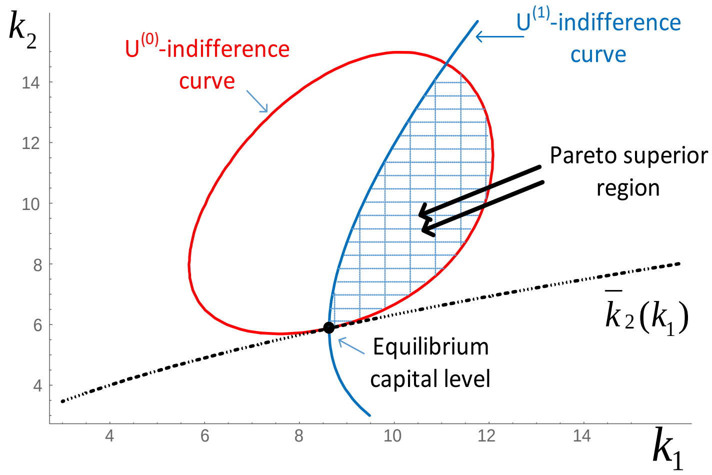

Figure 1: Equilibrium capital level and underinvestment problem without government intervention in the example with $f_i(k) = 10\sqrt{k}$ for i=0,1,2, $u(c) = \ln c$, $\delta = 1, \beta = 1/2, d = 100\%$, and $k_0 = 10$.

3.1. The model with dividend tax

With a dividend tax policy, the modified firm's budget constraint in periods 1 and 2 are

$$v_0 (1 + \tau_0) = A_0 F(K_0, N_0) - I_0 - w_0 N_0 - R_0 b_{-1} + b_0 + S_0, \tag{22}$$

$$v_1 (1 + \tau_1) = A_1 F(K_1, N_1) - I_1 - w_1 N_1 - R_1 b_0 + b_1 + S_1, \tag{23}$$

where $\tau_t > 0$ is the proportional dividend tax rate and $S_t > 0$ is a lump-sum tax in period t.[10] Under a revenue-neutral policy, the budget constraints satisfy $S_t = \tau_t v_t^*$, where v_t^* is the equilibrium dividend level in period t. In *Eqs.* (22) and (23), the lump-sum subsidy is applied to the corporation rather than the consumer. However, even if the lump-sum subsidy is imposed on the consumer, there would be no change in equilibrium allocations. In this case, the consumer's additional income will be compensated with lower dividend income; thus, there would no change in the consumer's after-tax income.

Under dividend taxes, the first-order conditions from the firm's period-1 maximization

[10] The dividend tax in our model is not applied in the last period ($t = 2$). Given that in the last period ($t = 2$) the firm does not need to have investment (zero investment), the dividend policy does not affect the investment decision. That is, in the last period, the dividend payout is the same as corporate income. Therefore, under a revenue neutral policy, the dividend tax does not affect the equilibrium outcome in period $t = 2$. To simplify the model, we did not consider dividend tax in period 2. However, the main result is invariant to adding that tax.

problem of *Eq.* (5) are

$$w_1 = A_1 F_2(K_1, N_1) \tag{24}$$

and

$$\frac{1}{1+\tau_1} = \frac{A_2 F_1(K_2, N_2) + (1-d)(1-\chi)}{R_2}. \tag{25}$$

The first-order conditions from the period-0 maximization problem of *Eq.* (8) is

$$w_0 = A_0 F_2(K_0, N_0), \tag{26}$$

and

$$\frac{1}{1+\tau_0} = \frac{A_1 F_1(K_1, N_1)}{R_1}\frac{1}{1+\tau_1} + (1-d)\frac{A_2 F_1(K_2, N_2) + (1-d)(1-\chi)}{R_1 R_2}. \tag{27}$$

From *Eq.* (25) and (27), we can derive the firm's demand for period-0 investment:

$$\frac{1}{1+\tau_0} = \left(\frac{A_1 F_1(K_1, N_1)}{R_1} + \frac{(1-d)}{R_1}\right)\frac{1}{1+\tau_1}. \tag{28}$$

In this economy, there exists an equilibrium, shown in the following lemma:

Lemma 1 *There exists an open set of $T \subset \mathbb{R}^2$ such that $T \ni (0,0)$ and for any $(\tau_0, \tau_1) \in T$, an equilibrium of this economy exists.*

Lemma 1 suggests that there exists an equilibrium with zero tax (or $(\tau_0, \tau_1) = (0,0)$) and with moderate levels of taxes around zero subsidy. However, if the values of the taxes, (τ_0, τ_1), are too large, dividends can diverge to a large negative value due to low investment costs, which results in negative income and thus nonexistent equilibrium. Therefore, this paper analyzes the impact of infinitesimal increases in subsidies from zero to small positive values. The equilibrium described in Lemma 1 satisfies the consumer's intrapersonal subgame described in subsection 2.2 and the firm's profit maximization problems in subsection 2.1.

3.2. Pareto-improving dividend tax policies

This subsection shows that dividend tax policy can resolve the underinvestment problem. Specifically, we show that there is always a tax plan (τ_0, τ_1) that moves the equilibrium capital level into the Pareto-superior region in Figure 1.

The result in Lemma 1 implies that where $(\tau_0, \tau_1) = (0,0)$, there is an equilibrium that satisfies the first and second-order conditions. This also implies that for infinitesimal variations of tax rates from zero to a small positive value, an equilibrium still exists. In the following lemma, we investigate how an infinitesimal increase in τ_0 affects the equilibrium capital level and welfare:

Lemma 2 *At an equilibrium with $(\tau_0, \tau_1) = (0, 0)$, a marginal increase in τ_0 increases the equilibrium capital level in both periods and the following equality is satisfied:*

$$\frac{dk_2^*}{d\tau_0} / \frac{dk_1^*}{d\tau_0} = \overline{k}_2'(k_1) = \overline{b}_1'(b_0).$$

This results in a decrease in the period-0 intertemporal utility but an increase in the future intertemporal utilities, so we have

$$\frac{dU^{(0)}}{d\tau_0} < 0, \frac{dU^{(1)}}{d\tau_0} > 0 \text{ and } \frac{dU^{(2)}}{d\tau_0} > 0. \tag{29}$$

First, it is straightforward by envelope theorem to show that the increase in τ_0 decreases period-0 firm value in Lemma 2. Lemma 2 also indicates that both k_1 and k_2 increase with a period-0 tax. Higher τ_0 increases the firm's demand for period-0 investment. The increased capital demand makes consumers save more (i.e., higher b_0) so that the equilibrium capital level k_1 rises. However, Lemma 2 also indicates that the equilibrium allocations are not Pareto improving with only a period-0 tax. The current consumer (in period 0) maximizes her intertemporal utility, which is rational based on the current consumer's perspective but is present-biased based on the future consumer's perspective. Therefore, the current tax policy, which distorts the current interest rate, would make the current consumer worse off but would make consumers in other periods better off.

To move the equilibrium capital level into the Pareto-superior region, the ratio of k_2 relative to k_1 should be rising higher than $\overline{k}_2'(k_1)$. This can be achieved with a period-1 tax. In the following lemma, we show how the period-1 tax affects the equilibrium investment plan:

Lemma 3 *At the equilibrium with $(\tau_0, \tau_1) = (0, 0)$, a marginal increase in τ_1 satisfies the following inequality:*

$$\overline{k}_2'(k_1)\frac{dk_1}{d\tau_1} < \frac{dk_2}{d\tau_1}, \tag{30}$$

which implies that there is an increase in the period-0 intertemporal utility, i.e.,

$$\frac{dU^{(0)}}{d\tau_1} > 0. \tag{31}$$

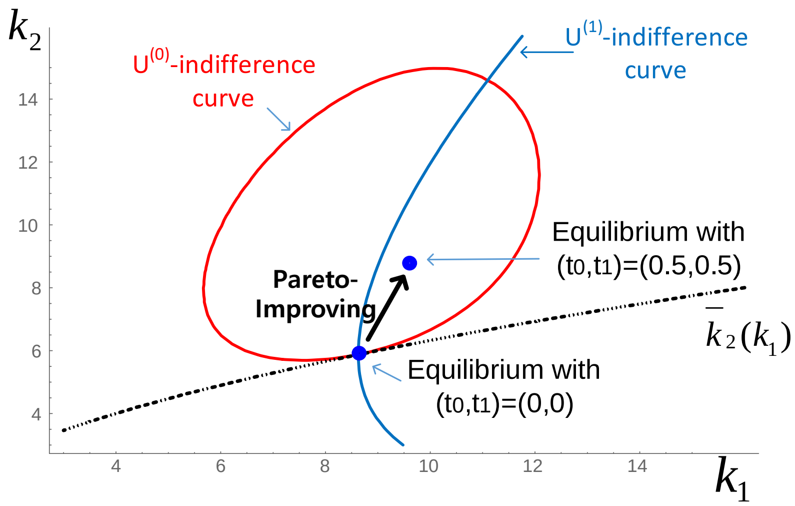

Figure 2: A Pareto-improving corporate tax policy with $(\tau_0, \tau_1) = (0.5, 0.5)$ in the example with $f_i(k) = 10\sqrt{k}$ for i=0,1,2, $u(c) = \ln c$, $\delta = 1, \beta = 1/2, d = 100\%$, and $k_0 = 10$.

This also results in a decrease in the period-1 firm value.

In Lemma 3, the inequality in *Eq.* (30) means that τ_1 raises the capital response function $\overline{k}_2(k_1)$, which means that any given k_1, k_2 under $\tau_1 > 0$ is greater than that under $\tau_1 = 0$. Therefore, Lemma 3 also implies that an increase in period-1 tax increases the period-1 saving level (b_1) for any given b_0. This increase in future savings (b_1) increases the future capital level (k_2), which has a positive impact on period-0 intertemporal utility.

From Lemmas 2 and 3, we can show the existence of Pareto-improving investment subsidy policies.

Proposition 1 *There exist dividend tax policies* $(\tau_0, \tau_1) \gg 0$ *that improve all intertemporal utilities.*

Proposition 1 indicates that implementing the tax policy in both periods can Pareto-improve the equilibrium allocations. $U^{(1)}$ and $U^{(2)}$ improve with a period-0 tax but $U^{(0)}$ does not. However, together with period-0 and period-1 taxes, all intertemporal utilities can improve. As shown in Figure 2, positive dividend taxes can let the equilibrium allocation move inside the Pareto-superior region in the given example. For detailed numerical results of the example, see Appendix A.

The two most prevalent welfare criteria for hyperbolic discounting models are the Pareto criterion that takes into account all periods' intertemporal utilities and the long-run perspective criterion (O'Donoghue and Rabin 1999, 2015) that considers the intertemporal utility in fictitious period -1. Proposition 1 uses the Pareto criterion, which takes into account intertemporal utilities across all periods. In our model, the long-run perspective preference would be

$$U^{(-1)} = \beta \left\{ \delta u(c_0) + \delta^2 u(c_1) + \delta^3 u(c_2) \right\}, \tag{32}$$

which is affinely equivalent to time-consistent preferences with a discounting factor of δ. As shown in Kang and Wang (2019) and Kang (2019), for general T-period time-separable utility with quasi-hyperbolic discounting, any policy improving intertemporal utilities across all periods also improves the long-term utility. Therefore, the policy proposed in Proposition 1 improves the long-run perspective preference utility, $U^{(-1)}$, as well.

Dividend tax policy improves welfare through a different mechanism than that of consumption tax (or capital subsidy), as introduced in previous literature (e.g., Laibson 1996). The consumption tax (with lump-sum subsidy) policy increases the equilibrium capital, as it raises the capital supply and subsequently decreases the equilibrium interest rate. However, the dividend tax is a demand-side policy that increases the equilibrium interest rate by raising the corporate demand for capital. This then pushes up the price of capital, resulting in higher interest rates in the economy. Holding income constant, the higher interest rates could lead the consumer to increase or decrease savings depending on the utility function (via the intertemporal elasticity of substitution). However, under a revenue neutral regime, the higher dividend tax would also increase the consumer's lump-sum subsidy from the government (in the case that the government provides the collected dividend taxes to the consumer in the form of subsidy) or dividend income (in the case the government provides the collected tax to the corporation). The higher lump-sum income and interest rates collectively lead the consumer to face higher compensated interest rate, which guarantees an increase in consumer saving. Therefore, the dividend tax policy can resolve the undersavings problem in the hyperbolic economy.

4. Corporate income tax

In this section, we show that the corporate income tax deteriorates the undersavings problem and thus decreases both firm value and consumer welfare. With a corporate income tax policy, the modified firm's budget constraints in periods 1 and 2 are

$$v_1 = A_1 F(K_1, N_1)\,(1-\theta_1) - I_1 - w_1 N_1 - R_1 b_0 + b_1 + M_1, \tag{33}$$

$$v_2 = A_2 F(K_2, N_2)\,(1-\theta_2) + (1-d)(1-\chi)K_2 - w_2 N_2 - R_0 b_1 + M_0, \tag{34}$$

where $\theta_t > 0$ is a proportional corporate income tax rate and $M_t > 0$ is a lump-sum subsidy in period t. Under a revenue-neutral policy, the budget constraints satisfy $M_t = \theta_t f_t(k_t^*)$, where k_t^* is the equilibrium capital level in period t.

From the firm's period-0 first-order conditions in terms of investment, we have

$$R_2 = A_2 F_1(K_2, N_2)\,(1-\theta_2) + (1-d)(1-\chi). \tag{35}$$

From the first-order conditions of the period-0 maximization problem, we have

$$\begin{aligned} R_1 &= A_1 F_1(K_1, N_1)\,(1-\theta_1) \\ &\quad +(1-d)\frac{A_2 F_1(K_2, N_2)\,(1-\theta_2) + (1-d)(1-\chi)}{R_2}. \end{aligned} \tag{36}$$

From *Eqs.* (35) and (36), we can derive the firm's inverse demand function for period-0 investment:

$$R_1 = A_1 F_1(K_1, N_1)\,(1-\theta_1) + (1-d). \tag{37}$$

From *Eqs.* (35) and (37), we know that corporate income taxes, in general, decrease the interest rate, which push down consumer's demand for savings. Thus, the underinvestment problem with hyperbolic discounting is larger with corporate income taxes, and consumer welfare decreases.

Following the same but converse logic as the dividend-taxation case in Section 4, an increase in θ raises the cost of investment relative to the cost of dividends.

Proposition 2 *There exist corporate income tax policies* $(\theta_0, \theta_1) \gg 0$ *that decrease all intertemporal utilities.*

Even though dividend taxation and corporate income taxation are structurally different under this setting, to prove the negative impact on welfare from corporate income tax in Proposition 2, we apply the analogous but converse logic as that of proof of Proposition 1. The increase in corporate income tax decreases the cost of dividend payout and raises the cost of investment, which is mathematically equivalent to the case of a decrease in dividend taxes. As corporate income tax increases, the investment level moves to the Pareto-inferior region, where the value of the firm for all periods is lower than the Nash equilibrium value without tax policy. This also implies that corporate income subsidies necessarily Pareto improve firm value.

5. Combination of the two policies

In previous sections, we considered dividend and corporate tax policies separately. However, in reality, the two types of taxes coexist in many countries. Thus, this section analyzes consumer welfare when the government use two corporate tax policies jointly. With two tax policies, the firm's budget constraints in periods 1, 2, and 3 are

$$v_0 (1+\tau_0) = A_0 F(K_0, N_0)(1-\theta_0) - I_0 - w_0 N_0 - R_0 b_{-1} + b_0 + S_0, \tag{38}$$

$$v_1 (1+\tau_1) = A_1 F(K_1, N_1)(1-\theta_1) - I_1 - w_1 N_1 - R_1 b_0 + b_1 + S_1, \tag{39}$$

and

$$v_2 (1+\tau_2) = A_2 F(K_2, N_2)(1-\theta_2) + (1-d)(1-\chi) K_2 - w_2 N_2 - R_2 b_1 + S_2, \tag{40}$$

where $S_t > 0$ is a lump-sum tax in period t. Under a revenue-neutral policy, the budget constraints satisfy $S_t = \tau_t v_t^* + \theta_t f_t(k_t^*)$, where v_t^* and k_t^* are the equilibrium dividend and capital levels, respectively, in period t. In this model, the dividend tax policy in period 2 (i.e., $\tau_2 > 0$) and the income tax policy in period 0 (i.e., $\theta_0 > 0$) does not affect equilibrium allocations.

With the same approaches as the previous two sections, we can derive the equilibrium interest rates in periods 2 and 3. Specifically, from the first-order conditions of the period-1 maximization problem, we have

$$R_2 = [A_2 F_1(K_2, N_2)(1-\theta_2) + (1-d)(1-\chi)](1+\tau_1). \tag{41}$$

From the first-order conditions of the period-0 maximization problem, we have

$$\begin{aligned} R_1 \quad = \quad & A_1 F_1(K_1, N_1)(1-\theta_1)\frac{(1+\tau_0)}{(1+\tau_1)} \\ & + (1-d)\frac{A_2 F_1(K_2, N_2)(1-\theta_2) + (1-d)(1-\chi)}{R_2}(1+\tau_0). \end{aligned} \tag{42}$$

From *Eqs.* (41-42), we have

$$R_1 = [A_1 F_1(K_1, N_1)(1-\theta_1) + (1-d)]\frac{(1+\tau_0)}{(1+\tau_1)}. \tag{43}$$

The necessary condition for Pareto-improvement is to increase savings in both period

0 and 1, as shown in the previous sections. One of the difficulties in welfare analysis under hyperbolic discounting is that intertemporal utilities are not smoothly concave due to time-inconsistency, and thus the existence of equilibrium is not globally guaranteed. To avoid this difficulty, we focus on local analysis for assessing the welfare effect from tax policies. *Eqs.* (41) and (43) show that corporate income and dividend taxes have opposite impacts on equilibrium interest rates. Therefore, to achieve a Pareto-improvement with the combined tax policy, the magnitude of the dividend tax should be strong enough compared to that of corporate income tax, which is shown in the following Proposition:

Proposition 3 *There always exists an open set,* $\Theta \subset \mathbb{R}^4$ *with* $\Theta \in 0$*, such that for any* $(\tau_0, \tau_1, \theta_1, \theta_2) \in \Theta$*, all intertemporal utilities with* $(\tau_0, \tau_1, \theta_1, \theta_2) > 0$ *and* $(\tau_0, \tau_1) > (\theta_1, \theta_2)$ *are higher than those with* $(\tau_0, \tau_1, \theta_1, \theta_2) = 0$.

Proposition 3 compares the welfare effects from two different economies: one economy with positive corporate income and dividend tax policies (i.e., $(\tau_0, \tau_1, \theta_1, \theta_2) > 0$) and the other without corporate taxes (i.e., $(\tau_0, \tau_1, \theta_1, \theta_2) = 0$). In Proposition 3, the condition $(\tau_0, \tau_1) > (\theta_1, \theta_2)$ implies that the dividend tax rates should be higher than corporate income tax rates to achieve Pareto-improvement. In the analysis, we define an open set $\Theta \subset \mathbb{R}^4$ to avoid the issue of non-existence of equilibrium in the hyperbolic economy. However, as shown in Laibson (1997), the existence of equilibrium is guaranteed with logarithmic utility in the infinite-period model, which will be introduced in the next section.

6. Steady state analysis

In this section, we introduce the steady-state analysis in an infinite-period model for investigating the impact of the two corporate tax policies on welfare and capital accumulation. We assume that there is a representative firm and consumer where both of them live for infinite periods.

6.1. The infinite-period model

The consumer lives for infinite periods. Therefore, the lifetime utility in period t is

$$U^{(t)}(c_t, c_{t+1}, \ldots) = u(c_t) + \beta \sum_{i=1}^{\infty} \delta^i u(c_{t+i}), \tag{44}$$

where we assume $u(c)$ is the CES instantaneous utility function:

$$u(c) = \begin{cases} \frac{c^{1-\rho}-1}{1-\rho} & if \quad \rho > 1, \\ \ln \rho & if \quad \rho = 1. \end{cases}$$

In a numerical analysis in the next subsection, we simply assume that the period-utility is a log function, i.e., $u(c) = \ln c$ for ensuring the existence of equilibrium. The representative consumer's budget constraint in year t is

$$c_t + b_t = w_t + v_t + R_t b_{t-1}.$$

We also assume that the firm lives for infinite periods. With the corporate tax policy, the firm's budget constraint in period t would be

$$v_t (1 + \tau_t) = A_t F(K_t, N_t)(1 - \theta_t) - I_t - w_t N_t - R_t b_{t-1} + b_t + S_t, \tag{45}$$

where $S_t = \tau_t v_t^* + \theta_t f_t(k_t^*)$, and v_t^* and k_t^* are the equilibrium dividend and capital levels, respectively. In each period t, the firm maximizes the present value of dividend payouts (i.e., the firm value in period t):

$$\max_{I_t, b_t} v_t + \frac{v_{t+1}}{R_{t+1}} + \frac{v_{t+2}}{R_{t+1} R_{t+2}} + \frac{v_{t+3}}{R_{t+1} R_{t+2} R_{t+3}} .... \tag{46}$$

We investigate how demand for investment is affected by the corporate tax policies in the infinite-period model. Taking derivative of the period-t firm value in terms of I_t, we have

$$\begin{aligned} & -\frac{1}{1+\tau_t} + \frac{A_{t+1} F_1(K_{t+1}, N_{t+1})(1 - \theta_{t+1})}{(1 + \tau_{t+1}) R_{t+1}} \\ & +(1-d) \frac{A_{t+2} F_1(K_{t+2}, N_{t+2})(1 - \theta_{t+2})}{(1 + \tau_{t+2}) R_{t+1} R_{t+2}} + (1-d)^2 \frac{A_{t+3} F_1(K_{t+3}, N_{t+3})(1 - \theta_{t+3})}{(1 + \tau_{t+3}) R_{t+1} R_{t+2} R_{t+3}} ... \\ = \quad & -\frac{1}{1+\tau_t} + \sum_{j=1}^{\infty} (1-d)^{j-1} \frac{A_{t+j} F_1(K_{t+j}, N_{t+j})(1 - \theta_{t+j})}{(1 + \tau_{t+j})} \left(\prod_{k=1}^{j} R_{t+k} \right)^{-1} = 0 \end{aligned} \tag{47}$$

Taking derivative of the period-(t+1) firm value in terms of I_{t+1}, we have

$$\begin{aligned} -\frac{1}{1+\tau_{t+1}} &+ \frac{A_{t+2}F_1(K_{t+2},N_{t+2})(1-\theta_{t+2})}{(1+\tau_{t+2})\,R_{t+2}} \\ +(1-d)&\frac{A_{t+3}F_1(K_{t+3},N_{t+3})(1-\theta_{t+3})}{(1+\tau_{t+3})\,R_{t+2}R_{t+3}} + ... = 0 \end{aligned} \tag{48}$$

From *Eqs.* (47-48). we have

$$-\frac{1}{1+\tau_t} + \frac{A_{t+1}F_1(K_{t+1},N_{t+1})(1-\theta_{t+1})}{(1+\tau_{t+1})\,R_{t+1}} + (1-d)\frac{1}{R_{t+1}}\frac{1}{1+\tau_{t+1}} = 0$$

which is equivalently,

$$R_{t+1} = \frac{1+\tau_t}{1+\tau_{t+1}}\left[A_{t+1}F_1(K_{t+1},N_{t+1})(1-\theta_{t+1}) + (1-d)\right]. \tag{49}$$

In the finite-period model assumed in the previous sections, with equal dividend taxes across periods, Pareto-improvement can be achieved. In the last period of the finite-period model, the firm does not make any decisions. This implies that the dividend tax in the last period does not decrease the marginal product of investment. However, in the infinite-period model, marginal product of investment is affected by all periods' dividend tax rates. Specifically, the period-t dividend tax decreases the relative marginal cost of investment but at the same time, period-(t+1) dividend tax decreases the marginal relative benefit of period-t investment. Therefore, as shown in *Eq.* (49), the tax rates in periods t and t+1 affects the interest rate in both ways, implying that uniform tax rates (i.e., $\tau_t = \tau_{t+1}$) does not change the equilibrium allocations in the infinite period model.

Therefore, in this section, we suggest decreasing tax rates such that $\tau_t > \tau_{t+1} > \tau_{t+2}....$ To derive a steady state analysis, $1+\tau_t$ should decrease proportionally. We define the proportional rate ($p > 1$) as

$$p = \frac{1+\tau_t}{1+\tau_{t+1}} \text{ for all } t = 0, 1, 2, ... \tag{50}$$

With a constant p, the steady state equilibrium exists. When p is greater than 1, the interest rate is greater than the marginal product of capital as shown in *Eq.* (49). With the higher interest rate, the consumer would increase or decrease savings depending on the value of intertemporal elasticity of substitution. However, in this model, the dividend tax is rebated into the consumer in the form of lump-sum subsidy or dividend income. Therefore, the higher interest rate has the same effect as increased compensated interest rate, and the policy raises the consumer's savings rate. For the corporate income tax rate, the steady-state equilibrium is well-defined with uniform tax, such as $\theta = \theta_t = \theta_{t+1} = \theta_{t+2} \cdots$. Therefore, we can characterize the steady state equilibrium in terms of (p, θ).

6.2. The steady state analysis

We consider a Cobb-Douglas production function:

$$Y_t = A_t K_t^{\alpha} N_t^{1-\alpha}. \tag{51}$$

From *Eqs.* (49) and (51), we can derive the equilibrium gross interest rate in year t as

$$R_t = \frac{1+\tau_{t-1}}{1+\tau_t}\left[\alpha \frac{Y_t}{K_t}(1-\theta_t) + (1-d)\right] = p\left[\alpha \frac{Y_t}{K_t}(1-\theta) + (1-d)\right] \tag{52}$$

Eq. (52) shows that decreasing dividend tax policy ($p > 1$) would push up the interest rate, which induces the consumer to save more. On the other hand, the increased corporate tax rate (i.e., $\theta > 0$) pushes down interest rates. We use the steady-state analysis as shown in Laibson (1997) and Kang and Ye (2021: Proposition 5). We have the following equation at the steady state from consumer's maximization problem (see Laibson 1996):

$$\lambda = 1 - \delta^{\frac{1}{\rho}} R^{\frac{1-\rho}{\rho}} \left[1 - \lambda(1-\beta)\right]^{1/\rho}, \tag{53}$$

where λ represents the consumption to wealth ratio.[11] The growth rate of A_t is assumed to be exogenously given as g_A. Thus, consumption, output, and capital grow at the rate of $g_A/(1-\alpha)\,(\equiv g)$ at the steady state and thus we have the following condition:

$$(1-\lambda)R = \exp(g). \tag{54}$$

From *Eqs.* (52), (53) and (54), we have the following steady-state equilibrium with the hyperbolic-discounting parameter (β):

$$R = \frac{-\delta\exp(g) + \beta\delta\exp(g) + \exp(g\rho)}{\beta\delta} \tag{55}$$

From *Eqs.* (52) and (55), we have

$$\frac{K}{Y} = \frac{p(1-\theta)\alpha\beta\delta}{\exp(g\rho) - (1-\beta)\delta\exp(g) - p\beta\delta(1-d)} \tag{56}$$

[11] Specifically, at the steady state, we have $c_t = \lambda W_t$, where W_t is the sum of capital and labor income.

The steady state capital-to-output ratio is increasing in p but decreasing in θ as shown in *Eq.* (56). With the same parameter choices in Laibson (1997), we set $\alpha = 0.36, d = 0.08, g = 0.02, \rho = 1, \delta = 0.981$. With these parameter choices, the capital-to-output ratio (K/Y) is 3 if there is no present bias (i.e., $\beta = 1$) and no tax policy (i.e., $\tau_t = \theta_t = 0$). If the consumer is rational, the model is the same as the conventional macroeconomic model. Therefore, any government intervention decreases welfare. Specifically, if $\beta = 1$, the optimal tax rule becomes $\theta = 8.6656(p-1)/p$ from Eq. (56). In this case, if there is no dividend tax (i.e., $p = 1$), the income tax should also be zero (i.e., $\theta = 0$), which aligns with the conventional idea of rational expectations model.

With a typical value of hyperbolic discounting factor, $\beta = 0.7$, the capital-to-output ratio is 2.8 without a tax policy, which can be derived from *Eq.* (56). *Eq.* (56) indicates that if the corporate tax policy follows the rule $p = 8.737/(8.667 - \theta)$, the economy can recover the capital loss from present bias. That is, the capital-to-output ratio would be recovered from 2.8 to 3, assuming $\beta = 0.7$.[12] The rule, $p = 8.737/(8.667 - \theta)$, indicates that without corporate income tax ($\theta = 0$), p should be 1.0081 as shown in Figure 3. Without dividend tax policy ($p = 1$), the optimal corporate tax rates would be $\theta = -7\%$, indicating negative corporate income taxes.[13] However, negative corporate tax rates in a real economy are not to be expected. Therefore, this implies that without dividend taxation, it is impossible to recover the capital loss from consumers' present bias only with corporate tax policy.

Kang and Ye (2021) calculated the welfare gain from the government policy, which induces the steady-state equilibrium capital-to-output ratio to be 3. Given that this paper assumes the same hyperbolic discounting time preferences for the representative consumer as Kang and Ye (2021), we can directly use the result in Kang and Ye (2021). As shown in that paper, if the corporate policy is aimed at making the capital-to-output ratio equal to 3 (i.e., the value assuming no present bias) and if the policy is initiated in period 0, the welfare gain is equivalent to having additional 4% of period-0 consumption good.

[12] Specifically, we use the following equation to derive the optimal tax rule:

$$3 = \frac{p \times 0.7 \times 0.36 \times (0.981) \times (1-\theta)}{\exp(0.02) - (1-0.7)(0.981)\exp(0.02) - p \times 0.7(0.981)(1-0.08)}$$

[13] This paper derives the steady state equation and the optimal tax policy rule for the general value of β. Therefore, the steady state exists for the case of rational consumers (i.e., β=1) and for any tax rate, including the negative income tax. However, the negative income tax cannot be optimal with rational consumers.

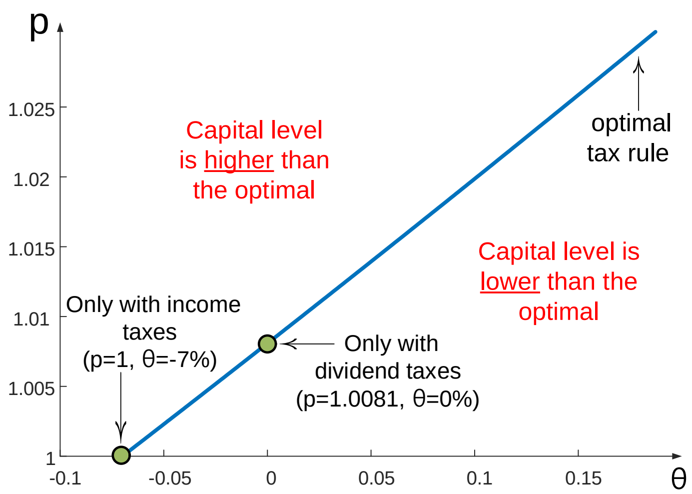

Figure 3: Optimal tax rule: $p = 8.737/(8.667 - \theta)$

Specifically, a 4% welfare gain means that $h = 0.04$ in the following equation:

$$u(c_0^* + c_0^* h) + \beta \sum_{\tau=1}^{\infty} \delta^\tau u(c_\tau^*) = u(c_0^+) + \beta \sum_{\tau=1}^{\infty} \delta^\tau u\left(c_\tau^+\right),$$

where $(c_0^*, c_1^*, \ldots)$ is the equilibrium consumption without policy ($p = 1$ and $\theta = 0$) and $(c_0^+, c_1^+, \ldots)$ is the one with policy ($p = 8.737/(8.667 - \theta)$).

7. Conclusion

This paper addresses the double taxation issue in a macroeconomic context under a Laibson-type hyperbolic discounting model. We show that dividend taxes can improve consumer welfare even though they decrease firm value in the hyperbolic economy, while corporate income taxes have a negative impact on both consumers and firms. In the model with a representative agent, the saving subsidy policy can result in the same equilibrium allocations as from the corporate tax policy. Therefore, in terms of welfare, there is no clear superiority of savings subsidy versus corporate tax. However, the main goal of this paper is to compare the benefits between dividend and corporate income policies. The main conclusion of this paper is that the dividend policy can be more effective than corporate income tax in improving welfare of the hyperbolic economy.

In this paper's framework, the corporation has ownership of capital, but the consumer has ownership of the corporation in the form of bonds and stocks. The consumers indirectly affect the corporation's budget through stock and bond markets. In this paper, the underinvestment problem is caused by consumers' low demand for corporate bonds, which would constrain the firm's cash to fund investments. Therefore, even though the firm is a rational decision maker, the economy with hyperbolic consumers cannot avoid the underinvestment problem.

This paper's approach is well-suited to analyze the linkage between corporate-level decisions and the macroeconomy. Conventional macroeconomic models often assume, for simplicity, that the firm rents capital from the consumer in every period. That setting would restrain the ability to assess government policies on corporate decisions. The analysis in this paper suggests that further research modeling corporate decision-making in the context of the macroeconomy would be warranted to better understand the broader implications of corporate decisions.

Appendices

A. An Example

In this example, we assume that $f_i(k) = 10\sqrt{k}$ for i=0,1,2, $u(c) = \ln c$, $\delta = 1, \beta = 1/2, d = 100\%, k_0 = 10$. The Euler equation from the consumer's period-1 maximization problem is

$$u'(c_1) = \beta\delta R_2 u'(c_2) \rightarrow \frac{1}{c_1} = \frac{1}{2} R_2 \frac{1}{c_2}. \tag{57}$$

From the firm's period-1 maximization problem, we have

$$R_2 = (1 + \tau_1) f_2'(k_2). \tag{58}$$

By the market clearing condition, we have

$$c_1 = f_1(k_1) - i_1 \text{ and } c_2 = f_2(k_2). \tag{59}$$

Given $d = 100\%$, we have $i_1 = k_2$ and $i_0 = k_1$. From *Eqs.* (57-59), we can get the capital response function:

$$\overline{k}_2(k_1) = \frac{A_1\sqrt{k_1}}{4/(1+\tau_1) + 1}. \tag{60}$$

We can solve for the equilibrium by deriving either $\overline{k}_2(k_1)$ or $\overline{b}_1(b_0)$. In this example, the functional form of $\overline{k}_2(k_1)$ is simpler, so we get the equilibrium from $\overline{k}_2(k_1)$ rather than $\overline{b}_1(b_0)$. However, we also derive $\overline{b}_1(b_0)$ in *Eq.* (72) below. The Euler equation from the consumer's period-0 maximization problem is

$$-u'(c_0) + \beta\delta u'(c_1)\left(R_1 - \overline{b}_1'(b_0)\right) + \delta u'(c_1)\overline{b}_1'(b_0) = 0. \tag{61}$$

From the firm's period-0 maximization problem, we have

$$R_1 = \frac{1+\tau_0}{1+\tau_1} f_1'(k_1). \tag{62}$$

From Lemmas 1 and 2, we know that $\overline{b}_1'(b_0) = \overline{k}_2'(k_1)$, and the Euler equation of *Eq.* (61) can be written as

$$\begin{aligned}&-u'(f\left({}_0(k_0) - i_0\right) + \beta\delta u'(f_1(k_1) - i_1)\left(\frac{1+\tau_0}{1+\tau_1} f_1'(k_1) - \frac{A_1\sqrt{k_1}}{4/\left(1+\tau_1\right)+1}\right)\\ &+\delta u'(f_2(k_2))\frac{A_1\sqrt{k_1}}{4/\left(1+\tau_1\right)+1} \quad = 0.\end{aligned} \tag{63}$$

From *Eq.* (63), we have

$$k_1 = 10\sqrt{k_0}\frac{6+3\tau_1+\tau_1^2+5\tau_0+\tau_0\tau_1}{22+19\tau_1+\tau_1^2+5\tau_0+\tau_0\tau_1}. \tag{64}$$

From Eqs (60) and (64), we can get the equilibrium capital levels; and thus the equilibrium consumption as a function of (τ_0, τ_1). Where $(\tau_0, \tau_1) = (0, 0)$, the equilibrium consumption and utility levels are $(c_0^*, c_1^*, c_2^*) = (22.9984, 23.4939, 24.2352)$ and $\left(U^{(0)}, U^{(1)}, U^{(2)}\right) = (6.3077, 4.7506, 3.1878)$. This paper shows that there is always $(\tau_0, \tau_1) \gg 0$ which Pareto-improves the economy. For example, where $(\tau_0, \tau_1) = (0.5, 0.5)$, the equilibrium consumption and utility levels are $(c_0^*, c_1^*, c_2^*) = (21.9985, 22.5622, 29.0875)$ and $\left(U^{(0)}, U^{(1)}, U^{(2)}\right) = (6.3343, 4.8014, 3.3703)$.

The following is the derivation of $\overline{b}_1(b_0)$ in the example. From the consumer's period-2 maximization problem, we have

$$u'(v_1 + w_1 + R_1 b_0 - b_1) = \beta\delta R_2 u'(v_2 + w_2 + R_2 b_1),$$

and, in turn,

$$\frac{1}{v_1 + w_1 + R_1 b_0 - b_1} = \frac{R_2}{2}\frac{1}{v_2 + w_2 + R_2 b_1}. \tag{65}$$

In equilibrium, we also have

$$R_2 = \left(1+\tau_1\right) f_2'(k_2) = \left(1+\tau_1\right)\frac{10}{2\sqrt{k_2}}, \tag{66}$$

and

$$v_2 + w_2 = f_2(k_2) - R_2 b_1. \tag{67}$$

Plugging *Eqs.* (66) and (67) into *Eq.* (65), we have

$$\frac{1}{v_1 + w_1 + R_1 b_0 - b_1} = \frac{\left(1+\tau_1\right)}{2}\frac{f_2'(k_2)}{f_2(k_2)} = \frac{\left(1+\tau_1\right)}{4}\frac{1}{k_2}. \tag{68}$$

By the commodity market clearing conditions, we have

$$c_1 = v_1 + w_1 + R_1 b_0 - b_1 = f_1(k_1) - k_2. \tag{69}$$

From *Eq.* (68) and (69), we have

$$\frac{1}{v_1 + w_1 + R_1 b_0 - b_1} = \frac{(1+\tau_1)}{4} \frac{1}{f_1(k_1) + (1-d)k_1 - (v_1 + w_1 + R_1 b_0 - b_1)},$$

which is equivalent to

$$v_1 + w_1 + R_1 b_0 - b_1 = \frac{4}{(1+\tau_1)} \left\{ f_1(k_1) + (1-d)k_1 - (v_1 + w_1 + R_1 b_0 - b_1) \right\}.$$

Thus, we have

$$b_1 = \frac{(v_1 + w_1 + R_1 b_0) - \frac{4}{(1+\tau_1)} \left\{ f_1(k_1) - (v_1 + w_1 + R_1 b_0) \right\}}{\frac{4}{(1+\tau_1)} + 1}. \tag{70}$$

By the market clearing condition, we have

$$c_0 = v_0 + w_0 + R_0 b_{-1} - b_0 = f_0(k_0) - k_1. \tag{71}$$

From *Eq.* (70) and (71), we have

$$\begin{aligned} \bar{b}_1(b_0) &= \frac{v_1 + w_1 + R_1 b_0}{4/(1+\tau_1) + 1} \\ &\quad - \frac{4/(1+\tau_1) \left\{ \begin{array}{c} f_1\left(f_0(k_0) - (v_0 + w_0 + R_0 b_{-1} - b_0)\right) \\ -(v_1 + w_1 + R_1 b_0) \end{array} \right\}}{4/(1+\tau_1) + 1}. \end{aligned} \tag{72}$$

Differentiating b_1 with b_0, we have

$$\bar{b}_1'(b_0) = \frac{R_1 - 4\left(f_1'(k_1) - R_1\right)/(1+\tau_1)}{4/(1+\tau_1) + 1} = \frac{R_1}{4/(1+\tau_1) + 1}, \tag{73}$$

which is the same as $\bar{k}_2'(k_1)$.

B. The proof of Lemma 1

The bond market clearing condition is satisfied because we use the same symbol (b_t) for both the consumer's and firm's budget constraints. The commodity market clearing condition is satisfied because the aggregate output in period t, $f_t(k_t)$, is the same as the consumer's total income plus investment in period $t \in \{0, 1\}$, $(v_t + w_t + R_t b_{t-1} - b_t) + I_t$ by the following. The firm's budget constraint is

$$(1-\tau_t)v_t = f_t(k_t) - I_t - w_t - R_1 b_{t-1} + b_t + S_t. \tag{74}$$

Under the revenue-neutral policy, we have $S_t = \tau_t v_t^*$, where the v_t^* is the equilibrium dividend payout in period t. Therefore, *Eq.* (74) in equilibrium can be reduced to

$$v_t = f_t(k_t) - I_t - w_t - R_1 b_{t-1} + b_t, \tag{75}$$

From *Eq.* (75), we have the following equation:

$$(v_t + w_t + R_t b_{t-1} - b_t) + I_t = f_t(k_t). \tag{76}$$

Eq. (76) implies that the commodity market clearing condition is satisfied because $(v_t + w_t + R_t b_{t-1} - b_t)$ is the same as c_t from the consumer's budget constraint.

The remaining proof is to show that for a small value of (τ_0, τ_1) near (0,0), (I) there exists an optimal plan for the firm's investment/dividend/labor levels for any given $R_t \in (0, \infty)$ and $w_t \in (0, \infty)$, (II) there exists a consumer's optimal savings level for any given $R_t \in (0, \infty)$, $w_t \in (0, \infty)$, $v_t \in \mathbb{R}$, and (III) R_t and w_t are finite and strictly positive in equilibrium. We can prove (III) directly from the following first-order conditions:

$$w_t = f_t(k_t) - k_t f_t'(k_t) \quad \text{for t=0,1,2} \tag{77}$$

$$R_1 = \frac{1+\tau_0}{1+\tau_1} \left\{ f_1'(k_1) + (1-d) \right\} > 0, \tag{78}$$

$$R_2 = (1+\tau_1) \left\{ f_2'(k_2) + (1-d)(1-\chi) \right\} > 0, \tag{79}$$

For the proof of (I), we have shown that the firm maximization problem is well-defined in the *Eqs.* (77-79). For the proof of (II), we can show that the consumer's maximization problem has a unique interior solution with given $R_t \in \mathbb{R}_{++}$, $w_t \in \mathbb{R}_{++}$, $v_t \in \mathbb{R}$:[14] In period 1, the representative consumer chooses b_1 to maximize its period-2 utility function given any (b_0, v_1, w_1, R_1):

$$\max_{b_1} u(c_1) + \beta\delta u(c_2) \tag{80}$$

subject to

$$c_1 = w_1 + v_1 + R_1 b_0 - b_1,$$

$$c_2 = w_2 + v_2 + R_2 b_1.$$

The first-order condition of the maximization problem of *Eq.* (80) is

$$-u'(c_1) + \beta\delta u'(c_2) R_2 = 0. \tag{81}$$

The second-order condition from the maximization problem of *Eq.* (80) is

$$u''(c_1) + \beta\delta u''(c_2) R_2^2 < 0. \tag{82}$$

By the first- and second-order conditions of *Eqs.* (81) and (82), we know that for any value of $b_0 \in (-(w_1 + v_1)/R_1, \infty)$, there exists a unique $b_1 \in \mathbb{R}$ that solves *Eq.* (81). We define $\overline{b}_1(b_0)$,

[14] In this paper, to avoid the complication of extra assumptions, we do not restrict the domain of dividends to be strictly positive but we allow negative values of dividends. For example, if the future productivity is extremely high, the firm makes a large investment so the dividend payout is negative. To restrict the range of the dividend payout requires additional assumptions on production functions.

which solves the first-order condition in *Eq.* (81), such that

$$-u'(w_1 + v_1 + R_1 b_0 - \bar{b}_1(b_0)) + \beta\delta u'(w_2 + v_2 + R_2\bar{b}_1(b_0))R_2 = 0. \tag{83}$$

Implicitly differentiating *Eq.* (83) with respect to b_0, we have

$$-u''(c_1)\left(R_1 - \bar{b}_1'(b_0)\right) + \beta\delta u''(c_2)R_2^2\bar{b}_1'(b_0) + \beta\delta u'(c_2)\frac{dR_2}{db_1}\bar{b}_1'(b_0) = 0, \tag{84}$$

Given $(v_1, w_1, R_1, b_0, k_1)$, an increase in b_1 increases the firm's investment, i_1; thus, we know that future capital k_2 increases from the firm's period-1 budget constraint. Therefore, the increase in b_1 affects the future interest rate R_2. Therefore, we have

$$\frac{dR_2}{db_1} = (1 + \tau_1)\, f_2''(k_2). \tag{85}$$

From *Eqs.* (84) and (85), we have

$$\bar{b}_1'(b_0) = \frac{u''(c_1)R_1}{u''(c_1) + \beta\delta R_2^2 u''(c_2) + \beta\delta u'(c_2)\,(1 + \tau_1)\, f_2''(k_2)} > 0. \tag{86}$$

Plugging $\bar{b}_1(b_0)$ into $U^{(0)}$, we obtain

$$\begin{aligned} U^{(0)} &= u(w_0 + v_0 + R_0 b_{-1} - b_0) + \beta\delta u(w_1 + v_1 + R_1 b_0 - \bar{b}_1(b_0)) \\ &\quad + \beta\delta^2 u(w_2 + v_2 + R_2\bar{b}_1(b_0)). \end{aligned} \tag{87}$$

By the limiting conditions of utility, such that $\lim_{c\to 0} u'(c) = \infty$ and $\lim_{c\to\infty} u'(c) = 0$, we know that the equilibrium capital level b_0 is bounded, i.e., $b_0 \in (w_0 + v_0 + R_0 b_{-1}, f_0(k_0) + (1-d)k_0)$. This implies that there exists an interior solution b_0 that satisfies the following first- and second-order conditions. The first-order condition is

$$-u'(c_0) + \beta\delta u'(c_1)\left(R_1 - \bar{b}_1'(b_0)\right) + \beta\delta^2 u'(c_2)R_2\bar{b}_1'(b_0) = 0, \tag{88}$$

and the second-order condition is

$$\begin{aligned} & u''(c_0) + \beta\delta u''(c_1)\left(R_1 - \bar{b}_1'(b_0)\right)^2 + \beta\delta u'(c_1)\left(\frac{1+\tau_0}{1+\tau_1} f_1''(k_1) - \bar{b}_1''(b_0)\right) \\ & + \beta\delta^2 u''(c_2)\left(R_2\bar{b}_1'(b_0)\right)^2 + \beta\delta^2 u'(c_2)\,(1 + \tau_1)\, f_2''(k_2)\left(\bar{b}_1'(b_0)\right)^2 \\ & + \beta\delta^2 u'(c_2)R_2\bar{b}_1''(b_0) \le 0. \end{aligned} \tag{89}$$

C. The proof of Lemma 2

The Euler equation from the period-1 maximization problem is

$$-u'(c_0) + \beta\delta u'(c_1)\left(R_1 - \bar{b}_1'(b_0)\right) + \beta\delta^2 u'(c_2)R_2\bar{b}_1'(b_0) = 0. \tag{90}$$

where

$$R_1 = \left(\frac{1+\tau_0}{1+\tau_1}\right) \times \{A_1 F_1(K_1, N_1) + (1-d)\}, \tag{91}$$

$$R_2 = (1+\tau_1) \times \{A_2 F_1(K_2, N_2) + (1-d)(1-\chi)\}$$

$$\begin{aligned} c_0 &= f_1(k_0) + (1-d)k_0 - k_1, c_1 = f_1(k_1) + (1-d)k_1 - k_2, \\ c_2 &= f_2(k_2) + (1-d)(1-\tau)k_2. \end{aligned} \tag{92}$$

Since we have $\overline{b}_1'(b_0) = \bar{k}_2'(k_1)$, the Euler equation in *Eq.* (90) can be expressed as a function of (k_1, k_2) :

$$-u'(c_0) + \beta\delta u'(c_1)\left(R_1 - \bar{k}_2'(k_1)\right) + \beta\delta^2 u'(c_2) R_2 \bar{k}_2'(k_1) = 0. \tag{93}$$

Implicitly differentiating (93) with τ_0, we have

$$\begin{aligned} &u''(c_0)dk_1 + \beta\delta u''(c_1)\left(f_1'(k_1) + (1-d) - \bar{k}_2'(k_1)\right)\left(R_1 - \bar{k}_2'(k_1)\right)dk_1 \\ &+\beta\delta u'(c_1)\left(\frac{1}{1+\tau_1}\right)\left(f_1'(k_1) + (1-d)\right)d\tau_0 + \beta\delta u'(c_1)\left(\frac{1+\tau_0}{1+\tau_1} f_1''(k_1) - \bar{k}_2''(k_1)\right)dk_1 \\ &+\beta\delta^2 u''(c_2)(1+\tau_1)\left(R_2\overline{k}_2'(k_1)\right)^2 dk_1 + \beta\delta^2 u'(c_2)(1+\tau_1) f_2''(k_2)\bar{k}_2'(k_1)\bar{k}_2'(k_1)dk_1 \\ &+\beta\delta^2 u'(c_2) R_2 \bar{k}_2''(k_1)dk_1 = 0. \end{aligned} \tag{94}$$

If $(\tau_0, \tau_1) = (0, 0)$, *Eq.* (94) is equivalent to

$$\begin{aligned} &u''(c_0)dk_1 + \beta\delta u''(c_1)\left(R_1 - \bar{k}_2'(k_1)\right)^2 dk_1 \\ &+\beta\delta u'(c_1)\left(f_1'(k_1) + (1-d)\right)d\tau_0 + \beta\delta u'(c_1)\left(f_1''(k_1) - \bar{k}_2''(k_1)\right)dk_1 \\ &+\beta\delta^2 u''(c_2)\left(R_2\overline{k}_2'(k_1)\right)^2 dk_1 + \beta\delta^2 u'(c_2) f_2''(k_2)\left(\bar{k}_2'(k_1)\right)^2 dk_1 \\ &+\beta\delta^2 u'(c_2) R_2 \bar{k}_2''(k_1)dk_1 = 0. \end{aligned} \tag{95}$$

Remembering the second-order condition in *Eq.* (89), at $(\tau_0, \tau_1) = (0, 0)$, we have

$$\begin{aligned} SOC &= u''(c_0) + \beta\delta u''(c_1)\left(R_1 - \overline{b}_1'(b_0)\right)^2 + \beta\delta u'(c_1)\left(f''(k_1) - \overline{b}_1''(b_0)\right)dk_1 \\ &\quad +\beta\delta^2 u''(c_2)\left(R_2\overline{b}_1'(b_0)\right)^2 dk_1 + \beta\delta^2 u'(c_2) f_2''(k_2)\left(\overline{b}_1'(b_0)\right)^2 dk_1 \\ &\quad +\beta\delta^2 u'(c_2) R_2 \overline{b}_1''(b_0)dk_1 \leq 0. \end{aligned} \tag{96}$$

From *Eqs.* (95) and (96), at $(\tau_0, \tau_1) = (0, 0)$, we have

$$\frac{dk_1}{d\tau_0} = -\frac{\beta\delta u'(c_1)\left(f_1'(k_1) + (1-d)\right)}{SOC} > 0. \tag{97}$$

Since a period-0 investment subsidy (τ_0) does not change the capital response function $\overline{k}_2(k_1)$, we have the following equality:

$$\frac{dk_2}{d\tau_0} / \frac{dk_1}{d\tau_0} = \overline{k}_2'(k_1). \tag{98}$$

Applying the envelope theorem to the period-0 intertemporal utility, we have

$$\frac{dU^{(0)}}{d\tau_0} = \frac{\partial U^{(0)}}{\partial k_1}\frac{dk_1}{d\tau_0} = -\frac{\partial U^{(0)}}{\partial c_1}\frac{dk_1}{d\tau_0} < 0. \tag{99}$$

The period-1 intertemporal utility is

$$U^{(1)}\left(f_1(k_1) + (1-d)k_1 - \overline{k}_2(k_1), f_2(\overline{k}_2(k_1)) + (1-d)(1-\chi)\overline{k}_2(k_1)\right). \tag{100}$$

Applying the envelope theorem to *Eq.* (100), we have

$$\frac{dU^{(1)}}{d\tau_0} = \frac{\partial U^{(1)}}{\partial k_1}\frac{dk_1}{d\tau_0} = \frac{\partial U^{(1)}}{\partial c_1}R_2\frac{dk_1}{d\tau_0} > 0. \tag{101}$$

The period-2 intertemporal utility is

$$U^{(2)} = u\left(f_2(\overline{k}_2(k_1)) + (1-d)(1-\chi)\overline{k}_2(k_1)\right). \tag{102}$$

Applying the envelope theorem to *Eq.* (102), we have

$$\frac{dU^{(2)}}{d\tau_0} = \frac{\partial U^{(2)}}{\partial k_2}\frac{dk_2}{dk_1}\frac{dk_1}{d\tau_0} = \frac{\partial U^{(2)}}{\partial c_2}\overline{k}_2'(k_1)R_2\frac{dk_1}{d\tau_0} > 0. \tag{103}$$

D. The proof of Lemma 3

Remembering the Euler equation in *Eq.* (81), we have

$$-u'(c_1) + \beta\delta R_2 u'(c_2) = 0, \tag{104}$$

where

$$\begin{aligned} R_2 &= (1+\tau_1)\times\{A_2F_1(K_2,N_2) + (1-d)(1-\chi)\}, \\ c_1 &= f_1(k_1) + (1-d)k_1 - \overline{k}_2(k_1), \\ c_2 &= f_2\left(\overline{k}_2(k_1)\right) + (1-d)(1-\chi)\overline{k}_2(k_1). \end{aligned} \tag{105}$$

Implicitly differentiating *Eq.* (104) with k_1, we have

$$-u''(c_1)\left(\frac{R_1}{1+\tau_1} - \bar{k}_2'(k_1)\right) + \beta\delta R_2^2 u''(c_2)\bar{k}_2'(k_1) + \beta\delta(1+\tau_1) f_2''(k_2)u'(c_2)\bar{k}_2'(k_1) = 0 \tag{106}$$

and, in turn, equivalently,

$$\bar{k}_2'(k_1) = \frac{u''(c_1)\frac{R_1}{1+\tau_1}}{u''(c_1) + \beta\delta R_2^2 u''(c_2) + \beta\delta(1+\tau_1) f_2''(k_2)u'(c_2)} > 0, \tag{107}$$

which is the same as $\bar{b}_1'(b_0)$.[15]

[15] This does not imply that $\bar{k}_2(k_1) = \bar{b}_1(b_0)$.

Implicitly differentiating *Eq.* (104) with τ_1, we have

$$u''(c_1)d\overline{k}_2(k_1) + \beta\delta R_2 u''(c_2)(1+\tau_1)\left(f_2'(k_2) + (1-d)(1-\chi)\right) d\overline{k}_2(k_1) \\ +\beta\delta u'(c_2)\left(f_2'(k_2) + (1-d)(1-\chi)\right) d\tau_1 = 0, \tag{108}$$

which is equivalent, in turn, to

$$\frac{d\overline{k}_2(k_1)}{d\tau_1} = -\frac{\beta\delta u'(c_2)(f_2'(k_2) + (1-d)(1-\chi))}{u''(c_1) + \beta\delta R_2 u''(c_2)(1+\tau_1)(f_2'(k_2) + (1-d)(1-\chi))}. \tag{109}$$

If $\tau_1 = 0$, *Eq.* (109) is reduced to

$$\frac{d\overline{k}_2(k_1)}{d\tau_1} = -\frac{\beta\delta u'(c_2)(f_2'(k_2) + (1-d)(1-\chi))}{u''(c_1) + \beta\delta R_2^2 u''(c_2)}. \tag{110}$$

Using second-order condition from *Eq.* (82), we have

$$u''(c_1) + \beta\delta u''(c_2)R_2^2 < 0. \tag{111}$$

From *Eqs.* (110) and (111), where $\tau_1 = 0$, we have

$$\frac{d\overline{k}_2(k_1)}{d\tau_1} > 0. \tag{112}$$

Implicitly differentiating $\overline{k}_2(k_1) = k_2$ in terms of τ_1, we have

$$\frac{d\overline{k}_2(k_1)}{d\tau_1} + \overline{k}_2'(k_1)\frac{dk_1}{d\tau_1} = \frac{dk_2}{d\tau_1}. \tag{113}$$

From *Eqs.* (112) and (113), we have

$$\overline{k}_2'(k_1)\frac{dk_1}{d\tau_1} < \frac{dk_2}{d\tau_1}. \tag{114}$$

In equilibrium, the period-0 intertemporal utility is

$$U^{(0)}\begin{pmatrix} f_0(k_0) + (1-d)k_0 - k_1, \\ f_1(k_1) + (1-d)k_1 - k_2, \\ f_2(k_2) + (1-d)(1-\tau)k_2 \end{pmatrix}. \tag{115}$$

By the envelope theorem, differentiating *Eq.* (115) with τ_1, we have

$$\frac{dU^{(0)}}{d\tau_1} = \frac{\partial U^{(0)}}{\partial k_2}\frac{d\overline{k}_2(k_1^*)}{d\tau_1} = \left\{-\beta\delta u'(c_1) + \beta\delta^2 u'(c_2)R_2\right\}\frac{d\overline{k}_2(k_1^*)}{d\tau_1}, \tag{116}$$

where k_1^* is the equilibrium period-1 capital level where $(\tau_0, \tau_1) = (0, 0)$. From *Eqs.* (81), (116) and (112), we have

$$\frac{dU^{(0)}}{d\tau_1} = (1-\beta)\delta u'(c_1)\frac{d\overline{k}_2(k_1^*)}{d\tau_1} > 0. \tag{117}$$

E. Proof of Proposition 1

By the commodity market clearing condition, we can define the intertemporal utilities as functions of capital levels, (k_1, k_2), such that

$$\begin{aligned}\overline{U}^{(0)}(k_1,k_2) &= U^{(0)}(f_0(k_0)+(1-d)k_0-k_1, \\ &\quad f_1(k_1)+(1-d)k_1-k_2, f_2(k_2)+(1-d)(1-\chi)k_2),\end{aligned} \tag{118}$$

$$\overline{U}^{(1)}(k_1,k_2) = U^{(1)}(f_1(k_1)+(1-d)k_1-k_2, f_2(k_2)+(1-d)(1-\chi)k_2), \tag{119}$$

and

$$\overline{U}^{(2)}(k_1,k_2) = U^{(2)}(f_2(k_2)+(1-d)(1-\chi)k_2). \tag{120}$$

We need to show that an increase in both τ_0 and τ_1 can improve all intertemporal utilities. We first check how the intertemporal utilities change with the level of capital (k_1, k_2). After that, we check how the utility changes with the policy (τ_0, τ_1).

Denote (k_1^*, k_2^*) as the equilibrium capital level where $(\tau_0, \tau_1) = (0, 0)$. At the equilibrium (k_1^*, k_2^*), we have the following inequalities from *Eqs.* (118-120):

$$\frac{\partial \overline{U}^{(2)}}{\partial k_1} = 0, \quad \frac{\partial \overline{U}^{(2)}}{\partial k_2} > 0. \tag{121}$$

$$\frac{\partial \overline{U}^{(1)}}{\partial k_1} > 0, \quad \frac{\partial \overline{U}^{(1)}}{\partial k_2} = 0. \tag{122}$$

$$\frac{\partial \overline{U}^{(0)}}{\partial k_1} < 0, \quad \frac{\partial \overline{U}^{(0)}}{\partial k_2} > 0. \tag{123}$$

The inequalities of *Eq.* (121) can be proven to be true directly from *Eq.* (120). The following are the proofs of the inequalities in *Eqs.* (122-123):

Taking derivative $\overline{U}^{(1)}$ with respect to k_1 at the equilibrium (k_1^*, k_2^*), we have

$$\frac{\partial \overline{U}^{(1)}}{\partial k_1}|_{(k_1,k_2)=(k_1^*,k_2^*)} = u'(c_1)(f_1'(k_1)+1-d) = u'(c_1)R_1 > 0. \tag{124}$$

Taking the partial derivative of $\overline{U}^{(1)}$ with respect to k_2, we have

$$\begin{aligned}\frac{\partial \overline{U}^{(1)}}{\partial k_2}|_{(k_1,k_2)=(k_1^*,k_2^*)} &= -u(c_1)+\beta\delta(f_2'(k_2)+1-d)u'(c_2) \\ &= -u(c_1)+\beta\delta R_2 u'(c_2),\end{aligned}$$

which is equivalent to the first-order condition in *Eq.* (81). Therefore, we have

$$\frac{\partial \overline{U}^{(1)}}{\partial k_2}|_{(k_1,k_2)=(k_1^*,k_2^*)} = 0. \tag{125}$$

The partial derivative of $\overline{U}^{(0)}$ with respect to k_1 is

$$\begin{aligned}\frac{\partial \overline{U}^{(0)}}{\partial k_1}|_{(k_1,k_2)=\left(k_1^*,k_2^*\right)} &= -u'(c_0)+\beta\delta u'(c_1)(f_1'(k_1)+1-d) \\ &= -u'(c_0)+\beta\delta u'(c_1)R_1.\end{aligned} \tag{126}$$

From *Eqs.* (88) and (126), we have

$$\frac{\partial \overline{U}^{(0)}}{\partial k_1}|_{(k_1,k_2)=\left(k_1^*,k_2^*\right)} = \beta\delta\left(u'(c_1)-\delta u'(c_2)R_2\right)\overline{k}_2'(k_1). \tag{127}$$

From *Eq.* (81), we have

$$u'(c_1)=\beta\delta R_2 u'(c_2). \tag{128}$$

From *Eqs.* (127) and (128), we have

$$\frac{\partial \overline{U}^{(0)}}{\partial k_1}|_{(k_1,k_2)=\left(k_1^*,k_2^*\right)} < 0.$$

Taking the partial derivative of $\overline{U}^{(0)}$ with respect to k_2 at the equilibrium $\left(k_1^*,k_2^*\right)$, we have

$$\begin{aligned}\frac{\partial \overline{U}^{(0)}}{\partial k_2}|_{(k_1,k_2)=\left(k_1^*,k_2^*\right)} &= -\beta\delta u'(c_1)+\beta\delta^2 u'(c_2)(f_2'(k_2)+1-d) \\ &= \beta\delta\left(-u'(c_1)+\delta u'(c_2)R_2\right).\end{aligned} \tag{129}$$

Remembering the first-order condition in *Eq.* (81), we have

$$-u'(c_1)+\beta\delta u'(c_2)R_2=0. \tag{130}$$

From *Eqs.* (129) and (130), we have

$$\frac{\partial \overline{U}^{(0)}}{\partial k_2}|_{(k_1,k_2)=\left(k_1^*,k_2^*\right)} > 0.$$

From *Eqs.* (121) and (122), we know that any marginal increase in k_1 would increase $U^{(1)}$ and $U^{(2)}$. However, from *Eqs.* (126) and (129), small increases in capital $(\Delta k_1, \Delta k_2)$ should satisfy the following inequality to induce a $U^{(0)}$ increase:

$$\frac{\Delta k_2}{\Delta k_1} > -\frac{-u'(c_0)+\beta\delta R_1 u'(c_1)}{\beta\delta\left(-u'(c_1)+\delta R_2 u'(c_2)\right)} > 0. \tag{131}$$

Remembering *Eq.* (88), we have

$$-u'(c_0)+\beta\delta u'(c_1)\left(R_1-\overline{b}_1'(b_0)\right)+\beta\delta^2 u'(c_2)R_2\overline{b}_1'(b_0)=0. \tag{132}$$

From *Eq.* (132), we know that the inequality in *Eq.* (131) is equivalent to

$$\frac{\Delta k_2}{\Delta k_1} > \overline{b}_1'(b_0), \tag{133}$$

which is also equivalent to $\Delta k_2/\Delta k_1 > \overline{k}_2'(k_1)$.

Therefore, if a small increase in (τ_0, τ_1) from $(0,0)$ to $(\Delta\tau_0, \Delta\tau_1)$ increases (k_1, k_2) in the same way as in *Eq.* (133), the policy would be Pareto-improving. From Lemma 2, we have

$$\frac{dk_2}{d\tau_0}\Delta\tau_0 = \overline{k}_2'(k_1)\frac{dk_1}{d\tau_0}\Delta\tau_0. \tag{134}$$

From Lemma 3, we have

$$\frac{dk_2}{d\tau_1}\Delta\tau_1 > \overline{k}_2'(k_1)\frac{dk_1}{d\tau_1}\Delta\tau_1. \tag{135}$$

From *Eqs.* (134) and (135), we have

$$\frac{dk_2}{d\tau_0}\Delta\tau_0 + \frac{dk_2}{d\tau_1}\Delta\tau_1 > \overline{k}_2'(k_1)\left(\frac{dk_1}{d\tau_0}\Delta\tau_0 + \frac{dk_1}{d\tau_1}\Delta\tau_1\right), \tag{136}$$

which is equivalent to the inequality in *Eq.* (133). Therefore, there always exists a Pareto-improving subsidy policy $(\tau_1, \tau_2) \gg 0$.

F. Proof of Proposition 2

For the existence of equilibrium, we can directly use the result in Lemma 1. Then, we can prove the Proposition with the same logic (in a reverse way) of the proof of Proposition E. In proposition E, the main forces that increase consumer's savings are higher interest rates, which is led by higher dividend taxes. However, income taxes decrease the real interest rates as shown below:

$$R_2 = A_2F_1(K_2, N_2)(1-\theta_2) + (1-d)(1-\chi) \text{ and}$$
$$R_1 = A_1F_1(K_1, N_1)(1-\theta_1) + (1-d).$$

Applying the reverse logic in Proposition 1, we can show that an increase in (θ_1, θ_2) moves the equilibrium capital level into the Pareto-inferior region.

G. Proof of Proposition 3

With combined tax policy, the gross interest rates in periods 1 and 2 should be

$$R_1 = \left(\frac{1+\tau_0}{1+\tau_1}\right) \times \{A_1F_1(K_1, N_1)(1-\theta_1) + (1-d)\}, \tag{137}$$

and

$$R_2 = (1+\tau_1) \times \{A_2F_1(K_2, N_2)(1-\theta_2) + (1-d)(1-\chi)\}. \tag{138}$$

For the convenience of the proof, we introduce new variables (ψ_0, ψ_1) and a constant (a) such that

$$\tau_0 = \psi_0 \text{ and } \theta_1 = a\psi_0,$$

and

$$\tau_1 = \psi_1 \text{ and } \theta_2 = a\psi_1.$$

With (ψ_0, ψ_1), we can prove Proposition 3 as showing that the necessary and sufficient condition for Pareto-improvement (in a small open set $\Phi \in 0$) is $a < 1$, which means that the dividend tax rates should be higher than the corporate tax rates.

In the same way as the proof of Lemma 2, we can derive the second-order condition of period-1 maximization problem in terms of ψ_0 (which is similar to *Eq.* (94)):

$$\begin{aligned}
&u''(c_0)dk_1 + \beta\delta u''(c_1)\left(f_1'(k_1) + (1-d) - \bar{k}_2'(k_1)\right)\left(R_1 - \bar{k}_2'(k_1)\right)dk_1 \\
&+\beta\delta u'(c_1)\left(\frac{1}{1+\tau_1}\right)\left(f_1'(k_1)(1-\theta_1) + (1-d)\right)d\psi_0 \\
&+\beta\delta u'(c_1)\left(\frac{1+\tau_0}{1+\tau_1}\right)f_1'(k_1)(-a)\,d\psi_0 \\
&+\beta\delta u'(c_1)\left(\frac{1+\tau_0}{1+\tau_1}f_1''(k_1)(1-\theta_1) - \bar{k}_2''(k_1)\right)dk_1 \\
&+\beta\delta^2 u''(c_2)\left(f_2'(k_2) + (1-d)(1-\chi)\right)R_2\left(\bar{k}_2'(k_1)\right)^2 dk_1 \\
&+\beta\delta^2 u'(c_2)(1+\tau_1)(1-\theta_2)f_2''(k_2)\left(\bar{k}_2'(k_1)\right)^2 dk_1 \\
&+\beta\delta^2 u'(c_2)R_2\bar{k}_2''(k_1)dk_1 \ = 0.
\end{aligned} \tag{139}$$

From *Eq.* (139), when $(\tau_0, \tau_1, \theta_1, \theta_2) = 0$, we have

$$\frac{dk_1}{d\psi_0} = -\frac{\beta\delta u'(c_1)\left[f_1'(k_1)(1-a) + (1-d)\right]}{SOC}, \tag{140}$$

where the second-order condition (SOC) is negative from *Eq.* (96). The sufficient condition for $dk_1/d\psi_0 > 0$ in *Eq.* (140) is $a < 1$.

Similarly as in the proof of Lemma 3, we can derive the second-order condition of period-2 maximization problem in terms of ψ_1 (which is similar to *Eq.* (108)):

$$\begin{aligned}
&u''(c_1)d\bar{k}_2(k_1) + \beta\delta R_2 u''(c_2)(1+\tau_1)\left(f_2'(k_2) + (1-d)(1-\chi)\right)d\bar{k}_2(k_1) \\
&+\beta\delta u'(c_2)\left(f_2'(k_2)(1-\theta_2) + (1-d)(1-\chi)\right)d\psi_1 \\
&+\beta\delta u'(c_2)\left((1+\tau_1)f_2'(k_2)(-a) + (1-d)(1-\chi)\right)d\psi_1 \ = 0.
\end{aligned} \tag{141}$$

From *Eq.* (141), we get the following relation when $(\tau_1, \theta_2) = 0:$

$$\frac{d\bar{k}_2(k_1)}{d\psi_1} = -\frac{\beta\delta u'(c_2)\left(f_2'(k_2)(1-a) + (1-d)(1-\chi)\right)}{u''(c_1) + \beta\delta R_2^2 u''(c_2)}. \tag{142}$$

The sufficient condition for $d\bar{k}_2(k_1)/d\psi_1 > 0$ in *Eq.* (142) is also $a < 1$.

The rest of proof is the same as those in Lemma 3 and Proposition 1. As shown in the proof of Proposition 1, the sufficient condition for Pareto-improvement in a small open area is to increase both k_1 and $\bar{k}_2(k_1)$. In the proof above, we showed that the policy in an open set Φ with $a < 1$ increases both k_1 and the function $\bar{k}_2(k_1)$.

References

Amromin, G., P. Harrison, and S. Sharpe (2008). How did the 2003 dividend tax cut affect stock prices? *Financial Management 37*(4), 625–646.

Angeletos, G.-M., D. Laibson, A. Repetto, J. Tobacman, and S. Weinberg (2001). The hyperbolic consumption model: Calibration, simulation, and empirical evaluation. *Journal of Economic Perspectives 15*(3), 47–68.

Brav, A., J. R. Graham, C. R. Harvey, and R. Michaely (2008). Managerial response to the may 2003 dividend tax cut. *Financial management 37*(4), 611–624.

Brown, J. R., N. Liang, and S. Weisbenner (2007). Executive financial incentives and payout policy: Firm responses to the 2003 dividend tax cut. *Journal of Finance 62*(4), 1935–1965.

Chetty, R. and E. Saez (2010). Dividend and corporate taxation in an agency model of the firm. *American Economic Journal: Economic Policy 2*(3), 1–31.

DellaVigna and Malmendier (2004). Contract design and self-control: Theory and evidence. *Quarterly Journal of Economics 119*(2), 353–402.

Dhaliwal, D., O. Z. Li, and R. Trezevant (2003). Is a dividend tax penalty incorporated into the return on a firm's common stock? *Journal of Accounting and Economics 35*(2), 155–178.

Edmans, A. (2009). Blockholder trading, market efficiency, and managerial myopia. *Journal of Finance 64*(6), 2481–2513.

Frederick, S., G. Loewenstein, and T. O'Donoghue (2002). Time discounting and time preference: A critical review. *Journal of Economic Literature 40*(2), 351–401.

Goldman, S. M. (1979). Intertemporally inconsistent preferences and the rate of consumption. *Econometrica 47*(3), 621–626.

Grenadier, S. R. and N. Wang (2007). Investment under uncertainty and time-inconsistent preferences. *Journal of Financial Economics 84*(1), 2–39.

Hanlon, M. and J. L. Hoopes (2014). What do firms do when dividend tax rates change? an examination of alternative payout responses. *Journal of Financial Economics 114*(1), 105–124.

Kang, M. (2019). Pareto-improving tax policies under hyperbolic discounting. *International Tax and Public Finance 26*(3), 618–660.

Kang, M. (2022). The positive impact of investment subsidies on the economy with present-biased consumers. *Quarterly Review of Economics and Finance 99*, 229–235.

Kang, M. and L. Wang (2019). Pareto criterion and long-term perspective criterion under myopic discounting. *Economics Bulletin 39*(1), 24–32.

Kang, M. and L. S. Ye (2019). Present bias and corporate tax policies. *Journal of Public Economic Theory 21*(2), 265–290.

Kang, M. and L. S. Ye (2021). Can optimism be a remedy for present bias? *Journal of Money, Credit and Banking* (1), 202–231.

Krusell, P., B. Kuruşçu, and A. A. Smith (2010). Temptation and taxation. *Econometrica 78*(6), 2063–2084.

Laibson, D. (1996). Hyperbolic discount functions, undersaving, and savings policy,. pp. National Bureau of Economic Research.

Laibson, D. (1997). Golden eggs and hyperbolic discounting. *Quarterly Journal of Economics 112*(2), 443–477.

Laibson, D., A. Repetto, and J. Tobacman (2007). Estimating discount functions with consumption choices over the lifecycle,. pp. National Bureau of Economic Research.

Loewenstein, G. and D. Prelec (1992). Anomalies in intertemporal choice: Evidence and an interpretation. *Quarterly Journal of Economics 107*(2), 573–597.

O'Donoghue, T. and M. Rabin (1999). Doing it now or later. *American Economic Review 89*(1), 103–124.

O'Donoghue, T. and M. Rabin (2015). Present bias: Lessons learned and to be learned. *American Economic Review: Papers and Proceedings 105*(5), 273–79.

Pavoni, N. and H. Yazici (2017). Optimal life-cycle capital taxation under self-control problems. *Economic Journal 127*(602), 1188–1216.

Phelps, E. S. and R. A. Pollak (1968). On second-best national saving and game-equilibrium growth. *Review of Economic Studies 35*(2), 185–199.

Strotz, R. H. (1956). Myopia and inconsistency in dynamic utility maximization. *Review of Economic Studies 23*(3), 165–180.

Thaler, R. (1981). Some empirical evidence on time inconsistency. *Review of Economic Studies 23*, 165–180.