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Improving the efficacy of carbon tax policies[☆]

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ABSTRACT

This paper examines the efficacy of carbon tax policies in view of the interactions between such policies and the firm's carbon efficiency and financing decisions. We show that because the government, unlike capital markets, does not price its policy's risk by taking into account default probabilities, the firm takes advantage of the government by using senior debt to minimize the carbon tax policy's cost. The shift to debt financing, in turn, mitigates the carbon tax policy's efficacy, resulting in lower carbon efficiency, thus higher carbon emissions. To remedy the government's predicament, we propose a correct-pricing rule that mimics market equilibrium conditions, thereby forcing firms to consider government interests. Such a rule renders senior debt no longer useful for reducing the carbon tax policy's cost. As a result, the tax policy's efficacy increases, hence reducing carbon emissions. Finally, we briefly consider and comment on the case of a social-welfare maximizing government that strategically chooses its carbon tax.

1. Introduction

Climate change has been an ongoing topic of political and policy debates for many years. While there is reasonable consensus about what drives climate change, there is less agreement about policy prescriptions to combat the phenomenon. Proposed policies aim to alter individuals' and firms' behaviour and provide incentives to innovate.¹ Some of these policies (such as technology or performance standards) are prescriptive, whereas others are market-based. Two policies seem to have emerged as popular among the market-based approaches: carbon taxation (CT) and cap-and-trade (CAT). Both aim to reduce carbon emissions by industry.² They try to do so directly or indirectly by using taxes, penalties, emission caps, carbon markets, incentives to innovate, etc. For example, Canada, South Africa, India, Taiwan, Costa Rica and most EU countries have introduced carbon taxes.³

Much attention has been given to the direct effects of such policies. Little attention, however, has been paid to the effects of such climate

change policies on firms' activities as a whole.⁴ Hence, often, the indirect effects of these policies have not been addressed adequately. Specifically, there has been little research on the effects of CR policies on firms' financing decisions.^{5,6} However, it is clear that policies whose aim is to reduce carbon emissions affect not just firms' production and innovation decision, but also financing decisions. More importantly, financing decisions, in turn, affect firms' carbon efficiency decisions and hence their carbon emissions. To properly assess the impact of CT policies, it is, therefore, necessary to consider the interactions between the firm's interdependent real (carbon-activity-related) and financial decisions and the government's carbon tax policies.⁷

⁴ Therefore, this paper is also related to the vast body of work on integrating financial and real decisions. See, for example, Titman (1984), Dotan and Ravid (1985), Brander and Lewis (1986), Brander and Spencer (1989), Appelbaum (1992), Aney et al. (2019).

⁵ The extent to which debtholders consider the firm's carbon-related risk is, empirically, studied by Jung et al. (2018). They show that there exists a positive association between the cost of debt and carbon risk.

⁶ Lundgren et al. (2015) empirically study the effect of carbon taxes on firms' productivity. They show that climate policy had a modest negative impact on technological development in the pulp and paper industry. They also show that the EU's Emission Trading System price on fossil fuels has created significant technological development incentives.

⁷ The effect of government taxation has been well addressed in the literature. However, the focus has usually been on the different treatment of equity and

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¹ See, for example, Grubler et al. (2002) and Nordhaus (2002).

² This paper does not deal with carbon-reducing policies aimed to affect individuals' behaviour.

³ Similarly, Australia, New Zealand, Japan, Canada, the US and the EU implemented CAT policies.

An important aspect of the interactions between carbon tax policies and firms is that the government is - and behaves - unlike other stakeholders. First, the firm's market stakeholders price their claims correctly: they price their risk by considering default probabilities. Second, they have well-defined opportunity costs. These two features are captured by capital market equilibrium conditions, which effectively force the firm to consider market stakeholders' interests whose participation is ensured by these conditions (hence, we can view them as participation constraints). Consequently, the firm cannot take advantage of its market claimants. Alternatively put, capital market equilibrium conditions ensure that only the "true costs" (namely, opportunity costs) of market participants matter.

On the other hand, the government does not price its risk⁸ and has no equilibrium condition equivalent to the capital market equilibrium condition. Moreover, it does not even have a clearly defined opportunity cost. As a result, firms can take advantage of a government not "protected" by market equilibrium conditions, but they cannot take advantage of market participants. At least in its spirit, this conclusion is related to the general result in game theory, where a non-strategic player is at a disadvantage when facing strategic rivals.⁹ In the context of policy choices, a similar result is shown in Appelbaum and Katz (1987), where strategic firms and strategic regulators take advantage of non-strategic consumers.¹⁰

In general, however, implications of the interactions between a non-strategic government/stakeholder and strategic market participants have received relatively little attention in the literature. A few studies examine non-market stakeholders' roles, but their focus was on their effects on social responsibility, engagement, reputation and branding.^{11,12}

The purpose of this paper is to examine the efficacy of carbon tax policies given the interactions between the firm's interdependent decisions and the government's carbon tax policies, recognizing that the government is and behaves, unlike market participants. In addition, we provide a possible remedy to the government's predicament that will prevent firms from taking advantage of the government. Consequently, the efficacy of the CT policy will increase.

We assume that the firm can finance its capital by using unsecured debt, secured debt and equity. We show that given the absolute and relative priority rules in most countries' bankruptcy laws, the firm can use secured debt to take advantage of the government. Secured debt allows the firm to take advantage of a government that does not price its risk because its claims have a higher priority than the government's claim. Unsecured debt cannot be used for this purpose because it has a lower priority than the government's claim. The fact that the firm can use secured debt to take advantage of the government implies that its value is no longer independent of its capital structure. We show that,

debt by tax rules. See, for example, De Angelo and Masulis (1980), Faccio and Xu (2015), Graham et al. (2015).

⁸ Note that, throughout the paper, the statement "the government does not price its policy risk" means that the government does not consider the probabilities that its claims (against the firm) will be in full or partial default.

⁹ This result has been shown theoretically and empirically, for example, by Camerer et al. (2004), Agranov et al. (2012), Brown et al. (2012) and Costa-Gomes and Crawford (2006).

¹⁰ It is also a basic result in Industrial Organization (for example, where, say, market "leaders" take advantage of fringe followers) and in bargaining theory (e.g., in Nash Bargaining, an agent's payoffs increase with her threat point).

¹¹ See Mahon and Wartick (2003), Amaeshi and Crane (2006), Rivera-Camino (2007).

¹² Within the context of the firm's financial decisions, a government that is and behaves, unlike other stakeholders, was first discussed in Appelbaum (1993). That paper shows that, with such an asymmetry, firms will, indeed, take advantage of the government by choosing a capital structure that minimizes the policy's cost (maximizes its benefits), thus explaining the firm's capital structure. The paper's focus, however, was strictly capital structure.

under these circumstances, the firm will be fully secure-debt-financed.¹³ The paper demonstrates that two conditions are necessary for the firm to take advantage of the government: (i) a government that does not price its risk, (ii) a debt class whose claim priority is higher than the government's priority.

This result has important implications regarding the efficacy of the carbon tax policy. Specifically, we show that the shift toward secured debt financing weakens the carbon tax policy's impact when the government does not price its tax correctly.

We then proceed to provide a possible solution to the government's predicament. Naturally, the solution is that the government should adopt a "correct pricing rule" that mimics market equilibrium conditions. The government can do so by pricing its claims in line with default probabilities. We show that by adopting such a rule, the government becomes yet another market stakeholder. Consequently, the firm would no longer be able to take advantage of the government. As with other stakeholders, a correct pricing rule forces the firm to consider the government's interest. It will do so by considering only the "true cost" of the government's carbon policy. In such a case, the firm's value becomes independent of its capital structure.¹⁴ More importantly, as a result, the carbon tax policy's efficacy increases.

Finally, we briefly discuss a possible framework for analyzing a scenario in which the government behaves strategically and chooses its carbon tax policy by maximizing social welfare.

2. Carbon tax

Consider a firm whose profit function is given by $\pi = \pi(k, x; \theta)$, where k is the capital input used in the production process, θ is a random variable that describes the state of the world, and x is the firm's level of carbon efficiency. We assume that θ is distributed over the interval $[0,1]$ according to the density function $g(\theta)$. We define θ so that a higher θ represents a better state of the world: $\partial\pi/\partial\theta > 0$.

The firm's carbon efficiency can represent its choice of technology, fuel type, product choice, etc.¹⁵ We define x so that a higher x represents greater carbon efficiency. Since, in general, higher carbon efficiency is more expensive, we have $\partial\pi/\partial x < 0$. In addition, we assume that the marginal cost of achieving greater carbon efficiency is increasing; namely, π is concave in x .¹⁶

The amount of carbon emitted by the firm's production process, defined as c , is given by the carbon emission "production function,"

$$c = F(x). \quad (1)$$

where $\partial F/\partial x < 0$, $\partial^2 F/\partial x^2 > 0$. This production function captures the fact that greater carbon efficiency reduces carbon emissions, but this reduction becomes increasingly difficult.

We assume that the government uses a simple carbon tax, given by the linear tax schedule:

$$T = ac \quad (2)$$

where $a \geq 0$ is the carbon tax rate. Thus, we have:

$$T = ac = aF(x) \equiv T(x) \quad (3)$$

where $\partial T/\partial x = a\partial F/\partial x < 0$, $\partial^2 T/\partial x^2 = a\partial^2 F/\partial x^2 > 0$.

¹³ It should be noted that, as is well known, we also get debt financing with corporate taxation. However, in that context, the result is not surprising because corporate taxation (with interest deductibility) directly changes the relative attractiveness of equity and debt (of any kind). Its objective is to raise revenues rather than alter the firm's activities/behaviour. On the other hand, carbon taxes do not directly change the relative attractiveness of equity and debt, and their objective is to increase carbon efficiency and not simply raise money.

¹⁴ In other words, the Modigliani-Miller theorem is restored. See Modigliani and Miller (1958).

¹⁵ Or, it may simply be directly related to the level of output.

¹⁶ Since we will not consider the choice of k , we do not need to worry about the concavity of the profit function in k .

3. Timeline and legal structure

The firm's problem has the following timeline. In "Stage 1," before θ is revealed, the firm chooses its capital, capital structure and carbon efficiency. We assume that the firm's capital can be financed by secured debt, unsecured debt and equity.¹⁷ To avoid making specific assumptions regarding the type of debt the firm can choose, or the claim-priority of the chosen debt, we allow the structure of debt to be chosen endogenously. Specifically, we allow the firm to choose the amounts of secured and unsecured debt.

In "Stage 2," after θ becomes known, the firm faces claims from its debtholders and the government. We assume that the firm must settle all claims in Stage 2. Define secured and unsecured debt levels as b_s and b_u , respectively. Let the corresponding contracted interest rates be given by r_s and r_u and let equity be given by e .

Once θ is revealed, the firm faces claims from debtholders and the government in the amount of $(1 + r_s)b_s + (1 + r_u)b_u + T(x)$. If the firm's assets are insufficient to meet its obligations fully, it defaults and goes into bankruptcy.

To avoid complications due to complex issues arising from restructuring/reorganizing processes¹⁸ (due to multilateral bargaining and strategic behaviour that, inevitable, occur in such processes), we focus on the case the firm faces liquidation.¹⁹ When the firm faces liquidation, its assets are sold off and distributed among the claimants under the protocol and rules established in the country's bankruptcy law.²⁰

For example, according to the bankruptcy protocols in most European countries as well as the U.S., Canada and other countries,²¹ the firm's assets and claims are paid in the order described in bankruptcy law. In most countries, secured creditors have the right to claim their assets or the security value. If their claims exceed the value of the security, they become unsecured creditors for the remainder. In the US, the priority rule among classes of claims is referred to as the absolute priority rule (APR). The division within a class of claimants with the same priority is known as the proportionate priority rule (PPR).²² Many EU countries do not explicitly incorporate these rules in the bankruptcy law, but they still distinguish among claimants' classes.²³ Often, the order is administrative expenses of bankruptcy (lawyers' fees, expenses related to the bankruptcy proceedings), taxes, wages and unsecured creditors. Equity holders are residual claimants. Bondholders, bank lenders, and trade creditors may be secured or unsecured creditors.²⁴ If many claimants, such as unsecured creditors, have the same priority, all are paid an equal fraction of their claims' face value.²⁵ The priority given to

governmental claims usually depends on their nature, the characteristics of competing claims and, likely, the jurisdiction involved. Consequently, often governmental claims have a lower priority than secured (and even unsecured) creditors.^{26,27} Interestingly, in the EU, it has been argued that governments should be given a high priority because not only is it more powerful than private claimants, but doing so would also decrease overall economy-wide benefits.²⁸ On the other hand, in North America, it was pointed out that even when governmental claims have a high priority, in practice, they often "get swept aside."²⁹ In any case, thus far, the question of governmental claims priority has not been fully settled in bankruptcy law.³⁰

Given the bankruptcy rules discussed above, we assume that claim priorities are as follows. Secured debtholders have priority with respect to the secured part of their claim. Hence, they receive the saleable value of the assets that are subject to security. But, if the security value is insufficient to satisfy their full claims, they are entitled to claim the remainder as unsecured creditors. We assume that, in this case, the government's claim has a higher priority than the unsecured (remainder) portion of the secured debtholders' claims, as well as the claims by unsecured debtholders.³¹ Finally, we assume that equity holders are residual claimants.

4. Claims

Secured debtholders have priority with respect to the secured part of their claim (b_s). But, the government's claim has priority over the unsecured portion of their claim ($r_s b_s$). Secured debtholders' receipts will, therefore, be:

$$b_s(\theta) = \begin{cases} (1 + r_s)b_s & \text{if } \theta \geq \theta^1 \\ b_s + r_s b_s \lambda & \text{if } \theta^2 \leq \theta \leq \theta^1 \\ b_s & \text{if } \theta^3 \leq \theta \leq \theta^2 \\ \pi(x, k, \theta) + k & \text{if } \theta \leq \theta^3 \end{cases} \quad (4)$$

where:

1. to simplify the presentation, we assume that $\pi(x, k, \theta) + k \geq 0$, for all θ .³²
2. the partial bankruptcy default states, θ^1 , θ^2 and θ^3 (where $\theta^1 \geq \theta^2 \geq \theta^3$), respectively, are implicitly defined by the equations,

$$\pi(x, k, \theta^1) + k - (1 + r_s)b_s - (1 + r_u)b_u - T = 0 \quad (5)$$

¹⁷ It is possible to introduce additional types of securities, including hybrid financing, but we do not pursue this in the paper. As will become clear later, adding hybrid financing will not alter the results in this paper. For an early model of secured and unsecured debt, see [Stulz and Johnson \(1985\)](#).

¹⁸ This is known in the U.S. as bankruptcy under Chapter 11.

¹⁹ Known in the U.S. as bankruptcy under Chapter 7.

²⁰ The same liquidation process occurs if negotiations and hence restructuring fails.

²¹ For European protocols, see [Ballerini \(2020\)](#), [McCormack et al. \(2016\)](#), [Brouwer \(2006\)](#) and [Van Den Berg \(2019\)](#). For U.S., law, see [Altman \(1983\)](#), [Willes \(1986\)](#), [White \(1980\)](#), [Warren \(1991\)](#). For Canada, see [Government of Canada \(1985\)](#).

²² For a discussion of these priority rules (including the question of how absolute they are), see, for example, [Grohsgal \(2017\)](#), [Rudzik \(2015\)](#), [Ballerini \(2020\)](#).

²³ See [Brouwer \(2006\)](#); [McCormack et al. \(2016\)](#). See also [Ballerini \(2020\)](#) for a discussion of the desirability of those rules in restructuring.

²⁴ They may also be partially secured creditors.

²⁵ In the US, these priorities are given in the US Code of Federal Regulations, Title 11 - Bankruptcy (11 U.S. Code §507, Priorities and 11 USC §505: Determination of tax liability). For more details, see: <https://www.govinfo.gov/content/pkg/USCODE-2017-title11/html/USCODE-2017-title11-chap5-subchap1-sec507.htm> <https://www.govinfo.gov/content/pkg/USCODE-2017-title11/html/USCODE-2017-title11-chap5-subchap1-sec505.htm> See also

[White \(1980\)](#). A similar treatment of secured debt exists in the Canadian Bankruptcy and Insolvency Act. See [Government of Canada \(1985\)](#).

²⁶ As is stated in US Code 11 USC §701-766, or in House Report no. 95-595, Subsection (b) governs tax liens: "The order of distribution of property subject to a tax lien is as follows: First, to holders of liens senior to the tax lien. For convenience, House Report no. 95-595 is provided in [Appendix A.1](#)."

²⁷ For example, in the particularly relevant case of liability for environmental damages, penalty claims may not be secured claims, thus giving rise to conflicts between governmental and other claims. See II U.S.C. § 724(b), 11 U.S.C. § 724(a) and II U.S.C. § 545. See also [Claar \(1992\)](#).

²⁸ See [McCormack et al. \(2016\)](#).

²⁹ This is pointed out by See [Ben-Ishai and Lubben \(2012\)](#).

³⁰ For a recent example, see the 2018 La Paloma Generating Company, LLC case described in [Appendix A.1.1](#). See also [Irvin and Kronenberg \(2018\)](#).

³¹ Even though this tilts results in favour of governmental carbon tax claims, we will show that the firm will still be able to take advantage of the government.

³² In principle, however, we could allow for $\pi(x, k, \theta) + k$ to be negative below some values of θ . For example, we could define θ^4 by the condition $\pi(x, k, \theta^4) + k = 0$. Then, the claims in [Eq. \(4\)](#) would have another row, such that $b_s(\theta) = 0$ for all $\theta \leq \theta^4$. This possibility would not add much to the discussion but would make it more cumbersome. The assumption that $\pi(x, k, \theta) + k \geq 0$, for all θ implies that the exists a lower bound to the firm's losses: $\pi(x, k, \theta) \geq -k$, adding an element of limited liability.

$$\pi(x, k, \theta^2) + k - b_s - T = 0 \tag{6}$$

$$\pi(x, k, \theta^3) + k - b_s = 0 \tag{7}$$

3. the (equal) fraction of the face value of the claims that secured and unsecured debtholders receive (for unsecured claims), defined as λ , is given by:

$$\lambda = \frac{\pi(x, k, \theta) + k - b_s - T(x)}{r_s b_s + (1 + r_u) b_u}, \quad 0 < \lambda < 1, \text{ for all } \theta^2 \leq \theta \leq \theta^1$$

Since the government's claims have priority over the unsecured portion of the secured debtholders' claims, as well as over unsecured debtholders' claims, its receipts, defined as $t(\theta)$, will be,

$$t(\theta) = \begin{cases} T(x) & \text{if } \theta \geq \theta^2 \\ \pi(x, k, \theta) + k - b_s & \text{if } \theta^3 \leq \theta \leq \theta^2 \\ 0 & \text{if } \theta \leq \theta^3 \end{cases} \tag{8}$$

Turning to unsecured debtholders, their receipts are given by:

$$b_u(\theta) = \begin{cases} (1 + r_u) b_u & \text{if } \theta \geq \theta^1 \\ \lambda(1 + r_u) b_u & \text{if } \theta^2 \leq \theta \leq \theta^1 \\ 0 & \text{if } \theta \leq \theta^2 \end{cases} \tag{9}$$

We assume that secured and unsecured debtholders are risk-neutral and face the same opportunity cost rate of return, ρ . In competitive capital markets, equilibrium requires that the net values of secured and unsecured debts should be zero, i.e.

$$E[b_s(\theta)] - (1 + \rho)b_s = 0. \tag{10}$$

$$E[b_u(\theta)] - (1 + \rho)b_u = 0. \tag{11}$$

In principle, we can solve conditions (10) and (11) for the equilibrium rates of interest, r_s , and r_u , that are required in order to be able to obtain secured and unsecured funds in the capital market. In particular, the capital market requires that r_s , and r_u be adjusted to take into account default probabilities correctly. In other words, equilibrium in the capital market requires that all debts are priced correctly. Alternatively, conditions (10) and (11) can be, simply, viewed as "participation constraints".

Equity holders, as residual claimants, will, therefore, receive,³³

$$e(\theta) = \begin{cases} \pi(x, k, \theta) + k - (1 + r_s)b_s - (1 + r_u)b_u - T(x) & \text{if } \theta \geq \theta^1 \\ 0 & \text{if } \theta \leq \theta^1 \end{cases} \tag{12}$$

4.1. The choice of capital structure

Given equity holders' receipts, as in Eq. (12), we can now derive the value of the firm. First, assuming that equity holders face the same opportunity cost rate of return, ρ , the net value of equity, VE , is given by,

$$VE = \frac{1}{(1 + \rho)} \{E[e(\theta)] - (1 + \rho)e\}. \tag{13}$$

Once we substitute the two capital market equilibrium conditions, given by (10) and (11), VE can be written as (see Appendix A.1):

$$VE(k, x, b_s) = (1 + \rho)^{-1} \{E[\pi(x, k, \theta)] - \rho k\} - \{E[t(\theta)]\} \equiv VF(k, x) - VG(k, x, b_s) \tag{14}$$

where,

³³ Implicitly, and for simplicity, we assume that there is limited liability of equity holders, namely: that $\pi(x, k, 0) \geq -e$, which implies that $\pi(x, k, \theta) \geq \pi(x, k, 0) \geq -e$, or $\pi(x, k, \theta) + e \geq 0$, for all θ .

$$VF(k, x) \equiv (1 + \rho)^{-1} \int_0^1 [\pi(x, k, \theta) - \rho k] g(\theta) d\theta = (1 + \rho)^{-1} \{E[\pi(x, k, \theta)] - \rho k\} \tag{15}$$

is the value of the firm in the absence of carbon taxes, and

$$VG(k, x, b_s) \equiv (1 + \rho)^{-1} \left[\int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s] g(\theta) d\theta + \int_{\theta^2}^1 T(x) g(\theta) d\theta \right] = (1 + \rho)^{-1} E[t(\theta)] \tag{16}$$

is the (expected) cost of the government's carbon tax policy.

The value of the firm, V , is given by the sum of the net values of equity and debt:

$$V = \frac{1}{(1 + \rho)} \{E[e(\theta)] - (1 + \rho)e\} + \{E[b_s(\theta)] - (1 + \rho)b_s\} + \{E[b_u(\theta)] - (1 + \rho)b_u\} \tag{17}$$

But, the capital market equilibrium conditions (10) and (11) require that the net value of both types of debt be zero. Thus, the value of the firm is:

$$V = \frac{1}{(1 + \rho)} \{E[e(\theta)] - (1 + \rho)e\} \equiv VE(k, x, b_s) \tag{18}$$

Or,

$$V = VF(k, x) - VG(k, x, b_s) \equiv V(k, x, b_s) \tag{19}$$

In other words, firm value maximization and equity value maximization are identical.

As can be easily seen in Eq. (15), in the absence of carbon taxes, the value of the firm, VF , is independent of its capital structure. Namely, neither the two types of debt nor equity appear separately in Eq. (15): they always enter jointly and symmetrically in k , i.e., $b_s + b_u + e = k$. Their effects on $VF(k, x)$ are, therefore, indistinguishable. On the other hand, in Eq. (16), we can see that, whereas b_s , b_u and e always enter symmetrically in k , secured debt also enters separately. In other words, VG is not symmetric with respect to b_s , b_u and e (note that θ^3 and θ^2 depend on b_s , but not on b_u). Their effects on $VG(k, x, b_s)$ are, therefore, not indistinguishable. Consequently, $VG(k, x, b_s)$ is not independent of the firm's capital structure.

The cost of the government's carbon tax policy, VG , is not independent of the firm's capital structure because, unlike the capital market, the government does not price its claim. Specifically, it does not adjust its tax claim to take into account the probabilities of tax default. Consequently, the firm's capital structure is determinate.

It is useful to note that because VF is independent of capital structure, whereas VG is not, it follows from Eq. (19) that in order to maximize its value, the firm must choose its capital structure to minimize the expected cost of the tax policy, VG , (this a necessary condition).

Since the choice of k is not the focus of this paper, we proceed by solving the firm's problem for a given value of k . Thus, in stage 1, holding k fixed, we solve the problem:

$$\max_{b_s, b_u, e, x} \{V(k, x, b_s) : b_s + b_u + e = k > 0\} \tag{20}$$

Assuming that a solution to problem (20) exists, define the solution (i.e., the firm's maximum function) as $J(k; a)$ and the optimal values of b_s , b_u , e , and x as $b_s(k, a)$, $b_u(k, a)$, $e(k, a)$ and $x(k; a)$. Now, note that we take k as fixed and, moreover, b_s , b_u and e enter symmetrically in k . Thus, to determine the firm's optimal capital structure, it suffices to consider the effect of b_s on the value of the firm.³⁴

³⁴ In general, of course, to solve the maximization problem, we need to consider all the Kuhn-Tucker conditions together. However, since (as will be shown) the optimal solution for b_s happens to be a corner solution, it is more convenient to examine the optimality conditions separately, regardless of the other variables' values.

From Eqs. (15), (16) and (19) we obtain (see Appendix A.2):

$$\frac{\partial V}{\partial b_s} = \frac{1}{(1 + \rho)} \int_0^{\theta^2} g(\theta) d\theta = \frac{1}{(1 + \rho)} G(\theta^2) > 0 \tag{21}$$

where $G(\theta^2)$ is the cumulative distribution function evaluated at θ^2 . Therefore, since V is everywhere strictly increasing in b_s , it follows that, for all values of x and $k > 0$, the firm chooses the highest possible value of b_s . Namely, it chooses: $b_s(k; a) = k > 0$, for all k (and $a > 0$). This implies that the firm will not use unsecured debt, or equity: $b_u(k, a) = 0$, $e(k, a) = 0$. Thus, we have:

Proposition 1. *With incorrectly priced government claims, the firm will be fully secured-debt financed.*

What is the intuitive reason for this result? It may be tempting to say that secured debt has a relative advantage, as a financing tool, because of the high priority of its claims. This, however, cannot be the full explanation for a simple reason: capital markets price both types of debt correctly, as is ensured by the two equilibrium conditions (10) and (11). Consequently, in the absence of the government’s policy, secured debt does not have an intrinsic advantage over unsecured debt or equity. Secured debt becomes advantageous only when the government is involved. To see this, note that without government taxation, when $a = 0$, we have $T(x) = 0$ so that $G(\theta^2) = 0$ (because $|\pi(x, k, \theta) + k - b_s| > 0$, for all θ) and hence $\frac{\partial V}{\partial b_s}$ is always zero: in other words, the firm’s capital structure is indeterminate.

The reason this tax policy leads to secured debt financing is that, unlike the capital market, the government does not price its risk and has no opportunity cost that needs to be met; hence it has no equilibrium condition equivalent to (10) and (11). As a result, the firm can take advantage of the government by using secured debt as a tool. Secured debt can serve as a tool for two reasons. First, it has a higher priority than the government’s claims and, therefore, higher secured debt increases the risk facing the government. Second, the increased government risk reduces the firm’s tax policy costs since the government does not price its risk. Secured debt can, therefore, be used to minimize the cost of the tax policy. Unsecured debt cannot do the same job because, having a lower priority than the government, changes in its level do not affect the government’s risk; hence unpriced risk cannot be exploited.

Thus, two conditions are necessary for our result: (i) a government that does not price its risk (and has no opportunity costs), (ii) a class of debt whose claim priority is higher than the government’s claim. Neither of these is sufficient, but together they are necessary and sufficient conditions. In other words, you need a stakeholder that you can take advantage of, as well as a tool to do so. If you have both, the secured debt financing result occurs. These are the proverbial means, motive and opportunity. Secured debt provides the means, a government that does not price its risks provides the opportunity, and a motive is omnipresent in economics and finance. The fact that capital structure can be used to exploit the government provides, in this example, a simple explanation of a deviation from the Modigliani-Miller Theorem.

4.2. The choice of carbon efficiency

Let us now consider the choice of carbon efficiency. Using Eqs. (15) and (16), we obtain (see Appendix A.2):

$$\frac{\partial V}{\partial x} = \frac{1}{(1 + \rho)} \left\{ \int_0^{\theta^3} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta^2}^1 \left[\frac{\partial \pi(x, k, \theta)}{\partial x} - \frac{\partial T(x)}{\partial x} \right] g(\theta) d\theta \right\} \tag{22}$$

Since $\partial \pi / \partial x < 0$ and $\partial T / \partial x < 0$, an interior solution is possible. Thus, assuming that there is an interior solution for x , we must have:

$$\frac{\partial V}{\partial x} = 0 \tag{23}$$

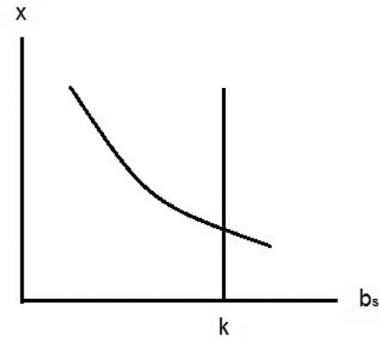


Fig. 1. Optimal Carbon Efficiency and Capital Structure.

In other words, we have:

$$\frac{\partial V}{\partial x} = \frac{1}{(1 + \rho)} \left\{ \int_0^{\theta^3} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta^2}^1 \left[\frac{\partial \pi(x, k, \theta)}{\partial x} - \frac{\partial T(x)}{\partial x} \right] g(\theta) d\theta \right\} = 0 \tag{24}$$

Let the solution to condition (24) be defined as $x(b_s, k; a)$.

Now, consider the effect of secured debt on the firm’s carbon efficiency.

From the result in the previous section, we know that $b_s = k$, for all values of x . Hence, the value of x does not affect the firm’s optimal capital structure. But, although the value of x does not affect the optimal capital structure, the converse is not true. That is, the firm’s capital structure does affect its carbon efficiency. To show this, note that (see Appendix A.3) the effect of b_s on $x(b_s, k; a)$ is given by (see Appendix A.3):

$$\frac{dx(b_s, k; a)}{db_s} = - \frac{\partial^2 V}{\partial x \partial b_s} / \frac{\partial^2 V}{\partial x^2} < 0. \tag{25}$$

In other words, we have:

Proposition 2. *An increase in secured debt decreases the firm’s carbon efficiency.*

Equation (25) simply gives us the slope of the first-order condition for x , in (b_s, x) space (assuming that there is an interior solution). It indicates that a higher secured debt leads to a lower carbon efficiency and, consequently, higher carbon emission. Since it is optimal for the firm to be fully financed with secured debt, this suggests that, at the equilibrium, carbon emissions will be at their maximum level for the given capital stock, k . Moreover, as k increases, b_s will also increase (so that $b_s = k$) and consequently, carbon emissions will increase.

These results can be seen in Fig. 1 below. The figure shows the firm’s two first-order conditions (in b_s, x space). The optimal capital structure is given by the vertical line, $b_s = k$ (for all values of x): since there is a corner solution, the optimal capital structure is independent of x . The optimal level of carbon efficiency, $x(b_s, k; a)$, for any level of b_s , is shown by the downward sloping curve (a reflection of equation (25)). The equilibrium levels of secured debt and carbon efficiency are given by: $\{b_s = k, x(k, k; a)\}$, the intersection of the two curves in Fig. 1.

It is useful to point out that, to the extent that the government has an emissions level target, it would not be able to meet its target if it did not consider the effects of the firm’s capital structure on its choice of carbon efficiency. Thus, the fact that carbon emissions depend on the firm’s capital structure suggests that some “fine-tuning” of the cap-and-trade policies can be useful. For example, policies that reduce the attractiveness of debt may be helpful. Such policies may focus on changing, or better enforcing, the priority of the government’s claims or requiring an installment to cover future governmental claims.³⁵

³⁵ See Claar (1992), Ben-Ishai and Lubben (2012).

Finally, before we conclude this section, notice that the effect of the tax rate, a , on the level of carbon efficiency is given by:³⁶

$$\frac{dx}{da} = -\frac{\partial^2 V}{\partial x \partial b_s} / \frac{\partial^2 V}{\partial x^2} > 0$$

Thus, a carbon tax can, indeed, affect carbon emissions. The efficacy and efficiency of the policy are, however, beyond the scope of this paper.

5. Correctly priced government claims

5.1. The value of the firm with correctly priced taxes

Before we examine the issue of incorrectly-priced government claims, it is useful to re-consider the other claimants. Debtholders can invest their funds ($b_i, i = s, u$) in a risk-free asset with a rate of return ρ and get $(1 + \rho)b_i$ at the end of the period. Their expected claims must, therefore, satisfy the requirement: $E[b_i(\theta)] \geq (1 + \rho)b_i, i = s, u$ (and in equilibrium, this holds with strict equality). In other words, we have a standard participation constraint. As such, it ensures that interest rates are correctly priced by taking into account debt default probabilities. On the other hand, the government does not price its risk, and its policy claim is not related to “assets” with opportunity costs; thus, it has no participation or a market equilibrium constraint. Consequently, the firm can take advantage of the government.

So, what should a correctly-priced government claim be? First, remember that the government’s expected claim is given by:

$$E[t(\theta)] = \left[\int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s]g(\theta)d\theta + \int_{\theta^2}^1 aF(x)g(\theta)d\theta \right] \quad (26)$$

But, since for all $\theta^3 < \theta < \theta^2$ we have $[\pi(x, k, \theta) + k - b_s] < aF(x)$, it is always the case that:

$$E[t(\theta)] < aF(x) \quad (27)$$

The simplest, most obvious way to correct the government’s asymmetry vis-à-vis market participants is (for the government) to adopt the same principle as the market does. That is, the government should charge a “correctly priced tax rate” that takes into account the probabilities of (full and partial) default on tax claims. For example, suppose there exists a “benchmark” carbon tax rate of β . This benchmark could be a rate applied to risk-free firms or based on an “average industry risk.” Alternatively, it could simply represent the government’s target or desired tax rate. Then, we can define the tax rate a^* to be a correctly-priced tax rate for a risky firm if it satisfies the condition:

$$\left[\int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s]g(\theta)d\theta + \int_{\theta^2}^1 a^*F(x)g(\theta)d\theta \right] = \beta F(x) \quad (28)$$

In other words, the correctly priced tax rate should be set as:

$$a^* = \frac{\beta F(x) - \int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s]g(\theta)d\theta}{\int_{\theta^2}^1 F(x)g(\theta)d\theta} \quad (29)$$

By definition, the correctly-priced tax rate, a^* , guarantees that the desired tax rate, β , is obtained. As is clear from Eq. (28), the correctly-price tax rate, a^* , must be such that $a^* > \beta$ (see Appendix A.4). In other words, the correctly-priced tax rate, a^* , takes into account the probabilities of full and partial default on government claims; it does so by charging the “risk premium” of $a^* - \beta > 0$.

With correctly-priced government tax claims, the net value of equity (and hence the net value of the firm) needs to be recalculated to take

³⁶ Since

$$\frac{\partial^2 V}{\partial x \partial a} = -\frac{1}{(1 + \rho)} \int_{\theta^2}^1 \frac{\partial F(x)}{\partial x} g(\theta)d\theta > 0,$$

and $\frac{\partial^2 V}{\partial x^2} < 0$.

into account condition (28). As is shown in Appendix A.5, the value of the firm is now given by:

$$V = \frac{1}{(1 + \rho)} \left[\int_0^1 \pi(x, k, \theta)g(\theta)d\theta - \rho k - \beta F(x) \right] \quad (30)$$

As is clear from Eq. (30), debt and equity do not appear separately in V . This brings us back to the Modigliani-Miller Theorem. Thus, we have:

Proposition 3. *With correctly-priced government tax claims, the firm’s value becomes independent of its capital structure.*

With correctly-priced government tax claims, the only costs that matter are the “true” costs of capital (ρk) and the true costs of the carbon tax policy ($\beta F(x)$), neither of which depends on capital structure. Since only the true costs of the government’s policy matter, the firm can no longer take advantage of the government by using secured debt. Now, the government is on an even playing field. The playing field is even because the government also has what may be viewed as its own version of a participation constraint.

5.2. Carbon efficiency with correctly priced taxes

Having obtained the value of the firm with correct tax-pricing, it is now useful to compare the firm’s choice of carbon efficiency under the two scenarios: with and without correct tax-pricing (denoted as CTP and NCTP, respectively). Define the solutions in the CTP and NCTP cases as $\{b_s^c(k) \in [0, k], b_u^c(k) \in [0, k], e^c(k) \in [0, k], x^c = x^c(k; \beta), b_s^c + b_u^c + e^c = k\}$ and $\{b_s^n = k, b_u^n = 0, e^n = 0, x^n = x^n(k, b_s^n; a) = x^n(k, k; a)\}$.

To compare the solutions, first note that, in contrast with the NCTP case, with CTP debt does not appear separately in V (in Eq. (30)), and as a result, the choice of carbon efficiency is also independent of capital structure (we have $x^c = x^c(k; \beta)$ as opposed to $x^n = x^n(k, b_s^n; a)$). Second, in the NCTP case, the carbon tax (a) was chosen arbitrarily. That is, it was not determined endogenously in the model (or by a known government policy decision rule that we could use to calculate its value). Specifically, we do not know the relationship between a and β . A “global” comparison of the firm’s carbon efficiency is, therefore, impossible. Consequently, it is not obvious which tax rate we should use for the comparison. Nevertheless, we know that, for any carbon tax and any given stock of capital (in the NCTP case), the firm will choose full secured-debt financing ($b_s = k$). Therefore, the level of b_s will be as high as possible for these given values of a and k . As a result, the carbon efficiency level will be as low as possible, given k and a . But, although global comparisons are impossible, in general, relatively higher values of β tend to make carbon efficiency higher in the CTP case. Specifically, the relationship between $x^c(k, \beta)$ and $x^n(k; a)$ and the effect of β on $x^c(k, \beta)$ are summarized by the following proposition: (proof is given in Appendix A.6):

- Proposition 4.** (i) $x^c(k, \beta) > x^n(k; a)$ only if $a < \frac{\beta}{1-G(\theta_n^2(k, a))}$
 (ii) $x^c(k, \beta) > x^n(k; a)$ if and only if $a < \beta < \frac{\beta}{1-G(\theta_n^2(k, a))}$
 (iii) $x^c(k, \beta) < x^n(k; a)$ if $a > \frac{\beta}{1-G(\theta_n^2(k, a))}$
 (iv) $\frac{dx^c}{d\beta} > 0$

Three final points are worth mentioning. First, while the correctly-priced tax scheme is intuitively appealing and works theoretically, the extent to which it is practical is beyond this paper’s scope. However, it should be pointed out that the informational requirements for correctly priced government tax claims are no different from those required for correct pricing by the market. The extent to which the market has an “informational-comparative-advantage” is an interesting empirical question.

Second, although this paper’s results were cast in the context of a carbon tax policy, it should be clear that the same results will be obtained for any government policy that fulfills the two requirements mentioned above. Namely: (i) the government does not price its policy-risk, but

other participants do, (ii) the firm can use a financing instrument whose claim priority is higher than the government's claim. These conditions provide means, motive and opportunity, so it is in the government's interest to address this issue.

Finally, an alternative to the correct tax pricing in this paper is discussed in the bankruptcy law literature. Specifically, it was suggested that the absolute priority rules (in bankruptcy) should be modified or better enforced.³⁷ This alternative, as Ben-Ishai and Lubben (2012) suggest, will allow the government to better "protect itself ex-ante" (legally). This paper shows that the government can protect itself ex-ante by simply mimicking market stakeholders' behaviour (even without changing priorities' rules).³⁸ Needless to say, the benefits of a government that behaves strategically, like other market players, extend beyond the particular issue addressed in this paper. A strategic government will always be in a stronger position vis-à-vis market forces, regardless of the interactions' nature.

6. A strategic government

In this section, we briefly explore the case of a strategic government. Specifically, we explicitly allow for the possibility that the government chooses its carbon policy, i.e., its target or desired tax rate, β , by maximizing social welfare.³⁹ Although a full discussion of this case is beyond the scope of this paper, we provide a general structure of a model with a strategic government.⁴⁰

In principle (in this context), social welfare should capture all direct and indirect costs and benefits of carbon emissions (including possible market failures). Hence, it should depend on the level of carbon emissions, which, in turn, depend on the firm's choice of carbon efficiency, x ,⁴¹ the firm's profits, the contribution of the firm's activities and tax revenues. Therefore, a reduced form of such a social welfare function can be written as a function of the two instruments available to the government and the firm: β and x , respectively. Denote this social welfare function as $W(x, \beta)$. Since this reduced form welfare function already includes all relevant carbon emissions considerations, the government's choice of an optimal β will also reflect these considerations. The firm's objective function is given by V , for example, as defined in Eq. (30) for the CTP case. We can denote it as $V(x, \beta)$.

The two most natural models to apply are the simultaneous move game and the sequential, leader-follower game. In a simultaneous move game, the government and firm simultaneously choose their instruments (target tax rate and carbon efficiency, respectively). In a sequential game, given the government's legislative powers, it would be natural for the government to assume the role of the leader. Thus, in the sequential game, the government chooses β first, and the firm chooses its carbon efficiency given the government's choice of β . As an example, we consider the sequential game and focus on the correct tax-pricing (CTP) case above.

The sequential, leader-follower game can be viewed as a two-stage game. Hence, applying backward induction, first, we solve the firm's problem (in "stage 2"). The firm's carbon efficiency choice in the CTP case is given (in the previous section) by $x^c = x^c(\beta)$.⁴² In other words, $x^c = x^c(\beta)$ is the firm's carbon efficiency best reply function. Given the

firm's best reply function, the government's problem (in the "first stage") is,

$$\max_{\beta} \{W(x^c, \beta) : x^c = x^c(\beta)\}$$

Or,

$$\max_{\beta} \{W(x^c(\beta), \beta)\} \quad (31)$$

Let the solution to the problem in Eq. (31) be denoted as β^* . The sequential game Nash equilibrium is, therefore, given by,

$$\beta^*, x^c(\beta^*).$$

Thus, whereas in the previous sections the target tax rate was an exogenous variable, arbitrarily chosen, now β^* reflects the equilibrium of a sequential move game, in which the government, as a leader, chooses its target tax rate optimally, given the firm's best reply function, while considering all the aspects of carbon emissions as captured by the social welfare function. Obviously, such a strategic government must be better off with the optimal target rate β^* compared to an arbitrary target rate, as discussed in previous sections. It is also clear that a strategic government that acts as a leader will be better off than a government that does not act as a leader.

Finally, since all the examples discussed in the previous sections can be viewed as the second stage in the two-stage leader/follower game, the corresponding results (obtained in the previous sections) do not change. Specifically, incorrect tax pricing will still give rise to a determinate capital structure (with full secured-debt financing) and may weaken the carbon tax policy's impact. Similarly, the firm's value will still be independent of its capital structure with correct tax pricing. This result was true for any arbitrary β , so it must also be true for β^* . Consequently, the firm's capital structure choice (in the CTP case) will not adversely affect carbon efficiency (and a higher β^* will tend to increase carbon efficiency).

We can, therefore, see that having a strategic government that acts as a leader shifts the power structure in favour of the government, resulting in a socially optimal target carbon tax (hence socially optimal carbon emissions), thus addressing the externalities problem and improving social welfare. However, the spirit of results in the previous sections does not change.

7. Conclusion

This paper examines the efficacy of the government's carbon tax policy. It shows that the government can be exploited because it does not price its risk and has no well-defined opportunity costs. Hence, it is not "protected" by a market equilibrium condition, as market stakeholders are. Consequently, if there is a class of debt with a higher claim priority than the government's claim, the firm will take advantage of the government by using such debt to minimize the policy's cost. As a result, the efficacy of the carbon tax policy decreases. We then show that if the government adopts a correct pricing rule that mimics market equilibrium conditions, it would become like other claimants and could no longer be exploited. A correct pricing rule, in turn, will increase the efficacy of the carbon tax policy.

Finally, we briefly examine a framework for analyzing the case of a social welfare maximizing government that chooses its carbon tax strategically.

Declaration of Competing Interest

None.

³⁷ See Claar (1992), Ben-Ishai and Lubben (2012).

³⁸ It may be interesting to examine the relative attractiveness of these two alternatives.

³⁹ Which, in turn, determines the correctly-price tax rate, a^* .

⁴⁰ This general structure is related to the model provided in Appelbaum and Katz (1987). In their paper, Appelbaum and Katz (1987) present a three-party policy choice model, where both the government and firms act strategically, whereas consumers do not.

⁴¹ Since $c = F(x)$.

⁴² For notational simplicity, we suppress the capital stock, K , in the definition of x^c . The firm's other optimal choices are given by $b_s^c \in [0, k]$, $b_u^c \in [0, k]$, $e^c \in [0, k]$, $b_s^c + b_u^c + e^c = k$.

Appendix A

A1. Legal appendix

House Report no. 95–595 states: “Subsection (b) governs tax liens. It is derived from section 67c(3) of the Bankruptcy Act [section 107(c)(3) of former title 11], without substantial modification in result. It subordinates tax liens to administrative expense and wage claims, and solves certain circuity of liens problems that arise in connection with the subordination. The order of distribution of property subject to a tax lien is as follows: First, to holders of liens senior to the tax lien; second, to administrative expenses, wage claims, and consumer creditors that are granted priority, but only to the extent of the amount of the allowed tax claim secured by the lien. In other words, the priority claimants step into the shoes of the tax collector. Third, to the tax claimant, to the extent that priority claimants did not use up his entire claim. Fourth, to junior lien holders. Fifth, to the tax collector to the extent that he was not paid under paragraph (3). Finally, any remaining property goes to the estate. The result of these provisions are to leave senior and junior lienors and holders of unsecured claims undisturbed. If there are any liens that are equal in status to the tax lien, they share *pari passu* with the tax lien under the distribution provisions of this Subsection.”

A1.1. La paloma generating company, LLC case

The importance of government claims became evident recently when, in one of the first decisions of its kind, the Bankruptcy Court for the District of Delaware ruled in a case involving La Paloma Generating Company, LLC (See [Irvin and Kronenberg, 2018](#)). The ruling stated that a power plant could be sold, under Section 363 of the bankruptcy code, free and clear of the debtor’s pre-sale obligations under California’s cap-and-trade program. However, this ruling was based on the specific language of the applicable California cap-and-trade (in fact, due to this ruling, the State of California Air Resources Board began to consider amendments to the state’s cap-and-trade regulations (see: <https://ww3.arb.ca.gov/regact/2018/capandtradehg18/isor.pdf>). In other words, the general principle, at least concerning cap and trade claims, is yet to be addressed (this problem can be viewed as an example of the more general issue of successor liability. See, for example, [Matheson \(2011\)](#)).

A2. The value of the firm with a carbon tax

Equilibrium in the secured debt capital market requires that:

$$E[b_s(\theta)] = (1 + \rho)b_s. \quad (\text{A.1})$$

Thus, from [Eq. \(A.1\)](#) we get:

$$(1 + \rho)b_s = \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta + \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta + \int_{\theta^2}^{\theta^1} [b_s + r_s b_s \lambda]g(\theta)d\theta + \int_{\theta^1}^1 (1 + r_s)b_s g(\theta)d\theta \quad (\text{A.2})$$

and therefore,

$$\int_{\theta^1}^1 (1 + r_s)b_s g(\theta)d\theta = (1 + \rho)b_s - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [b_s + r_s b_s \lambda]g(\theta)d\theta \quad (\text{A.3})$$

Equilibrium in the unsecured debt capital market requires that:

$$E[b_u(\theta)] = (1 + \rho)b_u. \quad (\text{A.4})$$

Thus:

$$(1 + \rho)b_u = \int_{\theta^2}^{\theta^1} [\lambda(1 + r_u)b_u]g(\theta)d\theta + \int_{\theta^1}^1 (1 + r_u)b_u g(\theta)d\theta$$

and therefore,

$$\int_{\theta^1}^1 (1 + r_u)b_u g(\theta)d\theta = (1 + \rho)b_u - \int_{\theta^2}^{\theta^1} [\lambda(1 + r_u)b_u]g(\theta)d\theta \quad (\text{A.5})$$

Now,

$$\begin{aligned} E[e(\theta)] &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k - (1 + r_s)b_s - (1 + r_u)b_u - T(x)]g(\theta)d\theta \\ &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^1}^1 (1 + r_s)b_s g(\theta)d\theta - \int_{\theta^1}^1 (1 + r_u)b_u g(\theta)d\theta \\ &\quad - \int_{\theta^1}^1 T(x)g(\theta)d\theta \end{aligned}$$

Thus, using conditions [\(A.3\)](#) and [\(A.5\)](#) we have:

$$\begin{aligned} &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k]g(\theta)d\theta \\ &\quad - \left\{ (1 + \rho)b_s - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [b_s + r_s b_s \lambda]g(\theta)d\theta \right\} \\ &\quad - \left\{ (1 + \rho)b_u - \int_{\theta^2}^{\theta^1} [\lambda(1 + r_u)b_u]g(\theta)d\theta \right\} \\ &\quad - \int_{\theta^1}^1 T(x)g(\theta)d\theta \end{aligned}$$

$$\begin{aligned}
 &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \left\{ \int_{\theta^1}^1 T(x)g(\theta)d\theta - \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta \right\} \\
 &\quad - \left\{ (1 + \rho)(b_s + b_u) - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [(b_s + r_s b_s \lambda) + (\lambda(1 + r_u) b_u)]g(\theta)d\theta \right\} \\
 &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \left\{ \int_{\theta^1}^1 T(x)g(\theta)d\theta + \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta \right\} \\
 &\quad - \left\{ (1 + \rho)(b_s + b_u) - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [b_s + \lambda(r_s b_s + (1 + r_u) b_u)]g(\theta)d\theta \right\}
 \end{aligned}$$

But, from definition of λ we have:

$$\begin{aligned}
 &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \left\{ \int_{\theta^1}^1 T(x)g(\theta)d\theta - \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta \right\} \\
 &\quad - \left\{ (1 + \rho)(b_s + b_u) - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [b_s + [\pi(x, k, \theta) + k - b_s - T(x)]]g(\theta)d\theta \right\} \\
 &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \left\{ \int_{\theta^1}^1 T(x)g(\theta)d\theta - \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta \right\} \\
 &\quad - \left\{ (1 + \rho)(b_s + b_u) - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [\pi(x, k, \theta) + k - T(x)]g(\theta)d\theta \right\} \\
 &= \int_{\theta^1}^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \left\{ \int_{\theta^2}^1 T(x)g(\theta)d\theta - \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta \right\} \\
 &\quad - \left\{ (1 + \rho)(b_s + b_u) - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [\pi(x, k, \theta) + k]g(\theta)d\theta \right\} \\
 &= \int_0^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta \\
 &\quad - \int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [\pi(x, k, \theta) + k]g(\theta)d\theta \\
 &\quad - \left\{ \int_{\theta^2}^1 T(x)g(\theta)d\theta - \int_{\theta^3}^{\theta^2} b_s g(\theta)d\theta \right\} \\
 &\quad - \left\{ (1 + \rho)(b_s + b_u) - \int_0^{\theta^3} [\pi(x, k, \theta) + k]g(\theta)d\theta - \int_{\theta^2}^{\theta^1} [\pi(x, k, \theta) + k]g(\theta)d\theta \right\} \\
 &= \int_0^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - \left\{ \int_{\theta^2}^1 T(x)g(\theta)d\theta + \int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s]g(\theta)d\theta \right\} \\
 &\quad - (1 + \rho)(b_s + b_u) \\
 &= \int_0^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - E[t(\theta)] - (1 + \rho)(b_s + b_u)
 \end{aligned}$$

$$\begin{aligned}
 VE &= \frac{1}{(1 + \rho)} \{ E[e(\theta)] - (1 + \rho)e \} \\
 &\quad \frac{1}{(1 + \rho)} \left\{ \int_0^1 [\pi(x, k, \theta) + k]g(\theta)d\theta - E(t(\theta)) - (1 + \rho)(b_s + b_u) - (1 + \rho)e \right\} \\
 &= \frac{1}{(1 + \rho)} \left\{ \int_0^1 [\pi(x, k, \theta) + k - (1 + \rho)(b_s + b_u + e)]g(\theta)d\theta - E(t(\theta)) \right\} \\
 &\quad \frac{1}{(1 + \rho)} \left\{ \int_0^1 [\pi(x, k, \theta) + k - (1 + \rho)k]g(\theta)d\theta - E(t(\theta)) \right\} \\
 &= \frac{1}{(1 + \rho)} \left\{ \int_0^1 [\pi(x, k, \theta) - \rho k]g(\theta)d\theta - E(t(\theta)) \right\}
 \end{aligned}$$

A3. Derivation of $\frac{\partial V}{\partial x}$

$$\frac{\partial VF}{\partial x} = \frac{1}{(1+\rho)} \int_0^1 \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta$$

$$\frac{\partial VG}{\partial x} = \frac{1}{(1+\rho)} \left\{ \int_{\theta^3}^{\theta^2} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta^2}^1 \frac{\partial T(x)}{\partial x} g(\theta) d\theta \right\}$$

Since $\pi(x, k, \theta^2) + k - b - T(x) = 0$ and $\pi(x, k, \theta^3) + k - b_s = 0$.

Thus,

$$\begin{aligned} \frac{\partial V}{\partial x} &= \frac{1}{(1+\rho)} \left\{ \int_0^1 \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta - \left[\int_{\theta^3}^{\theta^2} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta^2}^1 \frac{\partial T(x)}{\partial x} g(\theta) d\theta \right] \right\} \\ &= \frac{1}{(1+\rho)} \left\{ \int_0^{\theta^3} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta^2}^1 \left[\frac{\partial \pi(x, k, \theta)}{\partial x} - \frac{\partial T(x)}{\partial x} \right] g(\theta) d\theta - \right. \\ &= \left. \frac{1}{(1+\rho)} \left\{ \int_0^{\theta^3} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta^2}^1 \left[\frac{\partial \pi(x, k, \theta)}{\partial x} - \frac{\partial T(x)}{\partial x} \right] g(\theta) d\theta \right\} \right\} \end{aligned}$$

A4. The choice of capital structure

$$\begin{aligned} \frac{\partial V}{\partial b_s} &= -\frac{\partial VG}{\partial b_s} = \frac{1}{(1+\rho)} \left\{ \int_{\theta^3}^{\theta^2} g(\theta) d\theta \right\} - \left\{ \pi(x, k, \theta^2) + k - b_s - T(x) \right\} g(\theta^2) \frac{\partial \theta^2}{\partial b_s} \\ &+ \left\{ \pi(x, k, \theta^3) + k - b_s \right\} \frac{\partial \theta^3}{\partial b_s} \Bigg\} + \frac{\partial V}{\partial k} = \frac{1}{(1+\rho)} \int_0^{\theta^2} g(\theta) d\theta = \frac{1}{(1+\rho)} G(\theta^2) + \frac{dV}{dk} \end{aligned} \tag{A.6}$$

since, from the definition of θ^2 and θ^3 we have:

$$\pi(x, k, \theta^2) + k - b_s - T(x) = 0. \tag{A.7}$$

$$\pi(x, k, \theta^3) + k - b_s = 0$$

A5. The effect of b_s on $x(b_s, k; a)$

The effect of b_s on $x(b_s, k; a)$ is given by

$$\frac{dx(b_s, k; a)}{db_s} = -\frac{\partial^2 V}{\partial x \partial b_s} / \frac{\partial^2 V}{\partial x^2}. \tag{A.8}$$

The term in the nominator is,

$$\frac{\partial^2 V}{\partial x \partial b_s} = \frac{1}{(1+\rho)} \left\{ \left[\frac{\partial \pi(x, k, \theta^3)}{\partial x} g(\theta^3) \right] \frac{\partial \theta^3}{\partial b_s} - \left[\frac{\partial \pi(x, k, \theta^2)}{\partial x} - \frac{\partial T(x)}{\partial x} \right] g(\theta^2) \frac{\partial \theta^2}{\partial b_s} \right\} \tag{A.9}$$

where, $\frac{d\theta^2}{db_s} = 1 / \frac{\partial \pi(x, k, \theta^2)}{\partial \theta} > 0$, $\frac{d\theta^3}{db_s} = 1 / \frac{\partial \pi(x, k, \theta^3)}{\partial \theta} > 0$. Now, if there is an interior solution for x , condition (24) must hold.

But, since $\frac{\partial \pi(x, k, \theta)}{\partial x} < 0$, condition (24) cannot hold unless $\int_{\theta^2}^1 \left[\frac{\partial \pi(x, k, \theta)}{\partial x} - \frac{\partial T(x)}{\partial x} \right] g(\theta) d\theta > 0$. Thus, we must have: $\frac{\partial T(x)}{\partial x} < \frac{1}{[(1-G(\theta^2))]} \int_{\theta^2}^1 \frac{\partial \pi(x, k, \theta)}{\partial x}$.

This means that, for the second term in Eq. (A.9), we have:

$$\begin{aligned} \frac{\partial \pi(x, k, \theta^2)}{\partial x} - \frac{\partial T(x)}{\partial x} &> \frac{\partial \pi(x, k, \theta^2)}{\partial x} - \frac{1}{[(1-G(\theta^2))]} \int_{\theta^2}^1 \left[\frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta \right] \\ &= \int_{\theta^2}^1 \left[\frac{\partial \pi(x, k, \theta^2)}{\partial x} - \frac{\partial \pi(x, k, \theta)}{\partial x} \right] g(\theta) d\theta. \end{aligned}$$

It seems intuitive that higher costs of greater carbon efficiency will mitigate the marginal benefits of a better state of the world.⁴³ In other words, it seems reasonable that $\frac{\partial^2 \pi(x, k, \theta)}{\partial \theta \partial x} = \frac{\partial^2 \pi(x, k, \theta)}{\partial x \partial \theta} < 0$. Finally, the concavity of V implies that $\frac{\partial^2 V}{\partial x^2} < 0$.⁴⁴ Therefore, we have:

$$\frac{\partial \pi(x, k, \theta^2)}{\partial x} - \frac{\partial T(x)}{\partial x} > 0. \tag{A.10}$$

so that:

$$\frac{dx(b_s, k; a)}{db_s} < 0.$$

⁴³ Such a case occurs, for example, if θ enters the profit function multiplicably ($\pi(x, k, \theta) = \theta H(x, k)$).

⁴⁴ $\frac{\partial^2 V}{\partial x^2} = \frac{1}{(1+\rho)} \left\{ \int_0^{\theta^3} \frac{\partial^2 \pi(x, k, \theta)}{\partial x^2} g(\theta) d\theta + \left[\frac{\partial \pi(x, k, \theta^3)}{\partial x} g(\theta^3) \right] \frac{\partial \theta^3}{\partial x} + \int_{\theta^2}^1 \left[\frac{\partial^2 \pi(x, k, \theta)}{\partial x^2} - \frac{\partial^2 T(x)}{\partial x^2} \right] g(\theta) d\theta - \left[\frac{\partial \pi(x, k, \theta^2)}{\partial x} - \frac{\partial T(x)}{\partial x} \right] g(\theta^2) \frac{\partial \theta^2}{\partial x} \right\} < 0$, since $\frac{\partial^2 \pi(x, k, \theta)}{\partial x^2} - \frac{\partial^2 T(x)}{\partial x^2} < 0$ and $\frac{\partial \pi(x, k, \theta^2)}{\partial x} - \frac{\partial T(x)}{\partial x} > 0$, $\frac{d\theta^2}{dx} > 0$, $\frac{d\theta^3}{dx} > 0$.

A6. Risk premium of correctly priced tax

$$\left[\int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s] g(\theta) d\theta + \int_{\theta^2}^1 a^* F(x) g(\theta) d\theta \right] = \beta F(x)$$

$$a^* = \frac{\beta F(x) - \int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s] g(\theta) d\theta}{\int_{\theta^2}^1 F(x) g(\theta) d\theta} = \frac{\beta}{[1 - G(\theta^2)]} - \frac{\int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s] g(\theta) d\theta}{F[1 - G(\theta^2)]}$$

$$> \frac{\beta}{[1 - G(\theta^2)]} - \frac{\int_{\theta^3}^{\theta^2} a^* F(x) g(\theta) d\theta}{F[1 - G(\theta^2)]} = \frac{\beta}{[1 - G(\theta^2)]} - \frac{a^*[G(\theta^2) - G(\theta^3)]}{[1 - G(\theta^2)]}$$

Or,

$$a^* + \frac{a^*[G(\theta^2) - G(\theta^3)]}{[1 - G(\theta^2)]} > \frac{\beta}{[1 - G(\theta^2)]}$$

$$a^* \left[1 + \frac{[G(\theta^2) - G(\theta^3)]}{[1 - G(\theta^2)]} \right] = a^* \frac{1 - G(\theta^2) + G(\theta^2) - G(\theta^3)}{1 - G(\theta^2)} = a^* \frac{1 - G(\theta^3)}{1 - G(\theta^2)} > \frac{\beta}{[1 - G(\theta^2)]}$$

$$\rightarrow a^* > \frac{\beta}{[1 - G(\theta^3)]} > \beta$$

A7. Value of the firm with correct tax-pricing

The value of the firm without correct pricing is given by,

$$V = \frac{1}{(1 + \rho)} \left[\int_0^1 \pi(x, k, \theta) g(\theta) d\theta - \rho k \right] - \frac{1}{(1 + \rho)} \left[\int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s] g(\theta) d\theta + \int_{\theta^2}^1 a F(x) g(\theta) d\theta \right]$$

But, correct government pricing requires that:

$$E[t(\theta)] = \beta F(x)$$

In other words, we need:

$$E[t(\theta)] = \left[\int_{\theta^3}^{\theta^2} [\pi(x, k, \theta) + k - b_s] g(\theta) d\theta + \int_{\theta^2}^1 T(x) g(\theta) d\theta \right] = \beta F(x)$$

Thus, using this condition in the expression for V , we get:

$$V = \frac{1}{(1 + \rho)} \left[\int_0^1 \pi(x, k, \theta) g(\theta) d\theta - \rho k - \beta F(x) \right]$$

A8. Comparison of carbon efficiency

Define the two first order conditions in the CTP and NCTP cases as $\frac{\partial V^c}{\partial x} = 0$ and $\frac{\partial V^n}{\partial x} = 0$, respectively. These are given by:

$$\frac{\partial V^n}{\partial x} = \frac{1}{(1 + \rho)} \left\{ \int_0^1 \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta - \left[\int_{\theta^3}^{\theta^2} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta^2}^1 \frac{\partial T(x)}{\partial x} g(\theta) d\theta \right] \right\}$$

$$\frac{\partial V^c}{\partial x} = \frac{1}{(1 + \rho)} \left\{ \int_0^1 \left[\frac{\partial \pi(x, k, \theta)}{\partial x} - \beta \frac{\partial F(x)}{\partial x} \right] g(\theta) d\theta \right\}$$

Then, for any arbitrary value of x calculate the difference:

$$(1 + \rho) \left(\frac{\partial V^c}{\partial x} - \frac{\partial V^n}{\partial x} \right) = \left\{ -\beta \frac{\partial F(x)}{\partial x} + \int_{\theta^3}^{\theta^2} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + a \frac{\partial F(x)}{\partial x} \int_{\theta^2}^1 g(\theta) d\theta \right\} = \int_{\theta^3}^{\theta^2} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + a \frac{\partial F(x)}{\partial x} [1 - G(\theta^2)] - \beta \frac{\partial F(x)}{\partial x}$$

$$= \int_{\theta^3}^{\theta^2} \frac{\partial \pi(x, k, \theta)}{\partial x} g(\theta) d\theta + \{ a[1 - G(\theta^2)] - \beta \} \frac{\partial F(x)}{\partial x} = \int_{\theta^3}^{\theta^2} \left[\frac{\partial \pi(x, k, \theta)}{\partial x} - \beta \frac{\partial F(x)}{\partial x} \right] g(\theta) d\theta + \int_{\theta^2}^1 (a - \beta) \frac{\partial F(x)}{\partial x}$$

Then, using this equation, conditions (A.10) and $\frac{\partial^2 \pi(x, k, \theta)}{\partial x \partial \theta} < 0$ (from Appendix A.3), we have:

For all $a < \beta$:

$$\left[\frac{\partial \pi(x, k, \theta^2)}{\partial x} - \beta \frac{\partial F(x)}{\partial x} \right] > \left[\frac{\partial \pi(x, k, \theta^2)}{\partial x} - a \frac{\partial F(x)}{\partial x} \right] > 0$$

$$(a - \beta) \frac{\partial F(x)}{\partial x} > 0$$

Thus, for all x and all $a < \beta$

$$\frac{\partial V^c}{\partial x} - \frac{\partial V^n}{\partial x} > 0$$

Given the concavity of V in x , this implies that:

$$x^c > x^n$$

Define the solutions in the CTP and NCTP (n and c) cases as:

$$y^c \equiv \{b_s^c(k) \in [0, k], b_u^c(k) \in [0, k], e^c(k) \in [0, k], x^c = x^c(k, \beta), b_s^c + b_u^c + e^n = k\}$$

and

$$y^n \equiv \{b_s^n = k, b_u^n = 0, e^n = 0, x^n = x^n(k, b_s^n; a) = x^n(k, k; a)\}$$

Define the cutoff states $\theta_n^3(k, a)$ and $\theta_n^2(k, a)$ by the conditions:

$$\pi[x^n(k, k; a), k, \theta_n^2(k, a)] - aF[x^n(k, k; a)] = 0 \tag{A.11}$$

$$\pi[x^n(k, k; a), k, \theta_n^3(k, a)] = 0 \tag{A.12}$$

The first-order condition in the NCTP case (defined as FOCN), evaluated at the optimal point, is:

$$(1 + \rho) \frac{\partial V^n(y^n; a)}{\partial x} = \left\{ \int_0^{\theta_n^3(k, a)} \frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta_n^2(k, a)}^1 \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} - a \frac{\partial F(x^n(k, k; a))}{\partial x} \right] g(\theta) d\theta \right\} = 0 \tag{A.13}$$

The first-order condition in the CTP case (defined as FOCC), evaluated at the optimal point, is:

$$(1 + \rho) \frac{\partial V^c(y^c; \beta)}{\partial x} = \left\{ \int_0^1 \left[\frac{\partial \pi(x^c(k, \beta), k, \theta)}{\partial x} - \beta \frac{\partial F(x^c(k, \beta))}{\partial x} \right] g(\theta) d\theta \right\} = 0 \tag{A.14}$$

Suppose we evaluate FOCC at the solution for FOCN. This yields:

$$(1 + \rho) \frac{\partial V^c(y^n; \beta, a)}{\partial x} = \left\{ \int_0^1 \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} - \beta \frac{\partial F(x^n(k, k; a))}{\partial x} \right] g(\theta) d\theta \right\}$$

This can be written as:

$$(1 + \rho) \frac{\partial V^c(y^n; \beta, a)}{\partial x} = \int_0^{\theta_n^3(k, a)} \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta_n^2(k, a)}^{\theta_n^3(k, a)} \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta \right. \right. \\ \left. \left. + \int_{\theta_n^2(k, a)}^1 \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta - \beta \frac{\partial F(x^n(k, k; a))}{\partial x} \right] \right] \tag{A.15}$$

But, from (A.13) we have:

$$\left\{ \int_0^{\theta_n^3(k, a)} \frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta_n^2(k, a)}^1 \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} \right] g(\theta) d\theta \right\} = \int_{\theta_n^2(k, a)}^1 a \frac{\partial F(x^n(k, k; a))}{\partial x} g(\theta) d\theta$$

Then, plug this into (A.13):

$$(1 + \rho) \frac{\partial V^c(y^n; \beta, a)}{\partial x} = \int_{\theta_n^2(k, a)}^{\theta_n^3(k, a)} \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta + \int_{\theta_n^2(k, a)}^1 a \frac{\partial F(x^n(k, k; a))}{\partial x} g(\theta) d\theta - \beta \frac{\partial F(x^n(k, k; a))}{\partial x} \right] \tag{A.16}$$

$$= \int_{\theta_n^2(k, a)}^{\theta_n^3(k, a)} \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta + \frac{\partial F(x^n(k, k; a))}{\partial x} \left[\int_{\theta_n^2(k, a)}^1 a g(\theta) d\theta - \beta \right] \right] \tag{A.17}$$

$$= \int_{\theta_n^2(k, a)}^{\theta_n^3(k, a)} \left[\frac{\partial \pi(x^n(k, k; a), k, \theta)}{\partial x} g(\theta) d\theta + \frac{\partial F(x^n(k, k; a))}{\partial x} [a(1 - G(\theta_n^2(k, a))) - \beta] \right] \tag{A.18}$$

From condition (A.18) it follows that:

(i) Necessary condition

$$x^c(k, \beta) > x^n(k; a) \text{ only if } a < \frac{\beta}{1 - G(\theta_n^2(k, a))}$$

(ii) Necessary and sufficient condition:

$$x^c(k, \beta) > x^n(k; a) \text{ if and only if } a < \beta < \frac{\beta}{1 - G(\theta_n^2(k, a))}$$

(ii) Sufficient condition

$$x^c(k, \beta) < x^n(k; a) \text{ if } a > \frac{\beta}{1 - G(\theta_n^2(k, a))}$$

(iii) Effect of β

$$\frac{\partial^2 V^c}{\partial x \partial \beta} = - \frac{\partial F}{\partial x} > 0 \tag{A.19}$$

and therefore,

$$\frac{dx^c(k, \beta)}{d\beta} = - \frac{\partial^2 V^c}{\partial x \partial \beta} / \frac{\partial^2 V^c}{\partial x^2} > 0.$$

References

- Agranov, M., Potamites, E., Schotter, A., Tergiman, C., 2012. Beliefs and endogenous cognitive levels: an experimental study. *Games Econ. Behav.* 75 (2), 449–463.
- Altman, E.I., 1983. *Corporate Financial Distress*. John Wiley.
- Amaeshi, K.M., Crane, A., 2006. Stakeholder engagement: a mechanism for sustainable aviation. *Corp. Soc. Responsib. Environ. Manage.* 13 (5), 245–260.
- Aney, M.S., Appelbaum, E., Banerji, S., 2019. Firm boundaries and financing with opportunistic stakeholder behaviour. *J. Corp. Finance* 56, 437–457.
- Appelbaum, E., 1992. Bankruptcy, warranties and the firm's capital structure. *Int. Econ. Rev.* 33 (2).
- Appelbaum, E., 1993. Government policy and the firm's capital structure. *Eur Econ Rev* 37 (6), 1185–1196.
- Appelbaum, E., Katz, E., 1987. Seeking rents by setting rents: the political economy of rent seeking. *Econ. J.* 97 (387), 685–699.
- Ballerini, G., 2020. The priorities dilemma in the EU preventive restructuring directive: absolute or relative priority rule?. *Int. Insolv. Rev.*
- Ben-Ishai, S., Lubben, S., 2012. Involuntary creditors and corporate bankruptcy. *UBC Law Rev.* 45.2, 253–282.
- Brander, J.A., Lewis, T.R., 1986. Oligopoly, and financial structure: the limited liability effect. *Am. Econ. Rev.* 76, 956–970.
- Brander, J.A., Spencer, B., 1989. Moral hazard and limited liability: implications for the theory of the firm. *Int. Econ. Rev.* 30, 833–849.
- Brouwer, M., 2006. Reorganization in US and european bankruptcy law. *Eur. J. Law Econ.* 22.1, 5–20.
- Brown, A., Camerer, C., Lovallo, D., 2012. To review or not to review? Limited strategic thinking at the movie box office. *Am. Econ. J.* 4 (2), 1–26.
- Camerer, C., Ho, T.-H., Chong, J.K., 2004. A cognitive hierarchy model of games. *Q. J. Econ.* 119 (3), 861–898.
- Claar, G.E., 1992. The case for a bankruptcy code priority for environmental cleanup claims. *William Mitchell Law Rev.* 18 (1), 29–59.
- Costa-Gomes, M.A., Crawford, V., 2006. Cognition and behavior in two-person guessing games: an experimental study. *Am. Econ. Rev.* 96 (5), 1737–1768.
- De Angelo, H., Masulis, R., 1980. Optimal capital structure under corporate and personal taxation. *J. Financ. Econ.* 8, 3–29.
- Dotan, A., Ravid, S.A., 1985. On the integration of real and financial decisions of the firm under uncertainty. *J. Finance* 40, 501–517.
- Faccio, M., Xu, J., 2015. Taxes and capital structure. *J. Financ. Quant. Anal.* 50 (3), 277–300.
- Government of Canada, 1985. *Bankruptcy and Insolvency Act (BIA)*, (1985) <https://laws-lois.justice.gc.ca/eng/acts/b-3/FullText.html>.
- Graham, J.R., Leary, M.T., Roberts, M.R., 2015. A century of capital structure: the leveraging of corporate america. *J. Financ. Econ.* 118 (3), 658–683.
- Grohsgal, B., 2017. How absolute is the absolute priority rule in bankruptcy? The case for structured dismissals. *William Mary Bus. Law Rev.* 18 (3), 439–542.
- Grübler, A., Nakićenović, N., Nordhaus, W.D., 2002. *Technological Change and the Environment. Resources for the Future*, Washington, DC, USA.
- Irvine, K.W., Kronenberg, D.E., 2018. *Acquiring Bankrupt Energy Assets Clear of Compliance Obligations. Power Business & Technology for the Global Generation Industry*.
- Jung, J., Herbohn, K., Clarkson, P., 2018. Carbon risk, carbon risk awareness and the cost of debt financing. *J. Bus. Ethics* 150, 1151.
- Lundgren, T., Marklund, P., Samakovlis, E., Zhou, W., 2015. Carbon prices and incentives for technological development. *J. Environ. Manage.* 150, 393–403.
- Mahon, S.L., Wartick, S.L., 2003. Dealing with stakeholders: how reputation, credibility and framing influence the game. *Corp. Reput. Rev.* 6 (1), 19–35.
- Matheson, T., 2011. *Taxing Financial Transactions: Issues and Evidence March 2011, IMF Working Papers*. 11, 54.
- McCormack, G., Keay, A., Brown, S., Dahlgreen, J., 2016. Study on a new approach to business failure and insolvency: comparative legal analysis of the member states' relevant provisions and practices. In: *European Commission, Directorate-General for JUSTICE AND CONSUMERS*. (https://ec.europa.eu/info/sites/info/files/insolvency_study_2016_final_en.pdf), January 2016
- Modigliani, F., Miller, M., 1958. The cost of capital, corporation finance and the theory of investment. *Am. Econ. Rev.* 53, 433–442.
- Nordhaus, W.D., 2002. Modeling induced innovation in climate-change policy. In: *Technological Change and the Environment. Resources for the Future*, Washington, DC, USA.
- Rivera-Camino, J., 2007. Re-evaluating green marketing strategy: a stakeholder perspective. *Eur. J. Mark.* 41 (11/12), 1328–1358.
- Rudzik, F.F., 2015. A priority is a priority—except when it isn't. *Am. Bankruptcy Inst. J.* 16, 16.
- Stulz, R.M., Johnson, H., 1985. An analysis of secured debt. *J. Financ. Econ.* 14 (4), 501–521.
- Titman, S., 1984. The effects of capital structure on a firm's liquidation decision. *J. Financ. Econ.* 13, 137–151.
- Van Den Berg, S., 2019. The new european 'relative priority': an analysis of its impact in the EU restructuring directive and dutch insolvency regime. *Emerg. Mark. Restruct. J.* 9.
- Warren, E., 1991. A theory of absolute priority. *Annu. Surv. Am. Law.* 9.
- White, J.M., 1980. Public policy toward bankruptcy: me-first and other priority rules. *Bell J. Econ.* 11, 550–564.
- Willes, J.A., 1986. *Contemporary Canadian Business Law: Principles and Cases*, second ed. McGraw-Hill Ryerson, Toronto.