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Can Revenue Recycling Kill Green Technology?

Abstract

Carbon tax revenue recycling – returning tax revenue to firms or households that are covered by the carbon tax – can potentially increase political acceptance for carbon taxation and prevent undesirable distributional outcomes and off-shoring. This paper uses a stylized theoretical model to analyze the long-run effects of carbon tax revenue recycling in a sector where there are knowledge spillovers between firms. The paper shows that recycling tax revenue to polluting firms can impede incentives to invest in green technologies and, in some settings, completely curb green investment. This is the case even if the individual transfers are small relative to aggregate government revenues and not contingent on firm-level emissions or investment levels. The disincentive to invest when revenues are recycled arises because a firm investing in green technology may lower not only their own emissions, but also those of other firms, when there are knowledge spillovers between them. When revenues are recycled, the emission reductions from the rest of the industry will lower the transfer received by the investing firm.

JEL-Codes: H230, Q540, Q580.

Keywords: green transition, technological development, carbon tax, revenue recycling.

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1 Introduction

Linking the use of government revenue from carbon taxation directly to transfer schemes that are meant to compensate firms or households facing the tax, often called carbon tax revenue recycling, can potentially solve several challenges facing policy makers. However, if there are large knowledge spillovers between firms in an industry, the findings in this paper show that recycling of revenue from carbon taxation can impede green technological development. The key to this result is that green-technology investments in an individual firm will lower emissions, and subsequent carbon tax payments, across the industry when there are substantial technology spillovers. As a result, a firm developing new green technology may end up receiving a lower transfer through the revenue recycling scheme. Understanding this mechanism makes the firm more reluctant to invest.

The carbon tax is well-established as a key instrument for driving green technological development and mitigating climate change, but implementation is politically challenging.¹ There is a growing literature suggesting that revenue recycling may solve some of these challenges. Revenue recycling can alleviate concerns both for adverse distributional effects of carbon taxation for households or workers, and for off-shoring of targeted activity.² More generally, recent findings suggest that revenue recycling may increase the population's acceptance for carbon taxation.³

Revenue recycling schemes have already been introduced in several countries. In British Columbia, a revenue neutral carbon tax and recycling scheme was implemented already in 2008, and the Canadian system for pollution taxation has later been developed towards a fully revenue neutral system.⁴ Several countries or regions, including France, Germany, the United

¹See for example Pearce (1991), Fischer & Newell (2008), Sen & Vollebergh (2018) and Timilsina (2022).

 $^{^{2}}$ Cronin et al. (2019) and Beck et al. (2015) consider distributional effects, while Böhringer et al. (2024) and Yamazaki (2017) focus on effects on activity and off-shoring.

³See for example Dugstad et al. (2024), Muth (2023), Sommer et al. (2022), Beiser-McGrath & Bernauer (2019), Klenert et al. (2018), Dabla-Norris et al. (2023), Carattini et al. (2018), Douenne & Fabre (2022), Mildenberger et al. (2022) and Barrez (2024).

⁴See Beck et al. (2015) and https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/putting-price-on-carbon-pollution.html. Accessed September 25, 2024.

Kingdom, Denmark and the Netherlands, have implemented versions of bonus-malus schemes in the transport sector, with additional taxation of high-emission vehicles combined with tax rebates for low-emission vehicles.⁵ For emissions of NOx, versions of revenue recycling schemes for polluting industries have been used in both Sweden and Norway.^{6,7}

The main contribution of this paper is to show that revenue recycling of carbon tax revenue can impede investment in green technologies. The main mechanisms are illustrated in a stylized theoretical model, where carbon tax revenue is recycled to firms in a polluting industry. The transfer is designed to be lump-sum: each firm receives an equal share of the total revenue. In the short-run equilibrium in the model, firms abate until their marginal abatement cost equals the carbon tax, and the revenue recycling scheme does not affect firm behavior or equilibrium emission levels.

In the long-run equilibrium, however, firms can invest in green technology that allows the firm to lower their emissions without using the existing, costly abatement technology. The key assumption is that development of green technology in one firm can, to some extent, be used also by the other firms in the industry. There is a large literature documenting such knowledge spillovers between firms, with a key contribution from Bloom et al. (2013).⁸ In the long-run equilibrium, the carbon tax will not only induce abatement by use of the known technology, but will also induce investments in the new green technology. However, the revenue recycling scheme will now affect equilibrium investments. More specifically, recycling of tax revenue will weaken the positive effect of the carbon tax on investment. For a given carbon tax, the higher the share of government revenue that is recycled, the lower will green investments be in equilibrium. Indeed, if spillovers are large enough, full revenue recycling may completely eliminate investments in the new green technology.

The intuition behind the result is simple: When there are knowledge spillovers, an individual firm making an investment in the new technology knows that the investment will reduce not

 $^{{}^{5}}$ Équiterre (2020).

⁶https://www.noxfondet.no/en/articles/about-the-nox-fond/. Accessed September 25, 2024.

⁷https://www.iea.org/policies/1198-nitrogen-oxides-nox-charge. Accessed September 25, 2024.

⁸See also Jaffe (1986), Jones & Williams (1998), Jaffe et al. (2005), Aghion & Jaravel (2015) and Rahko & Alola (2024).

only their own emissions, but also emissions, and subsequent tax payments, from other firms. As a result, the total tax revenue, of which the investing firm will receive a share through the revenue recycling scheme, will shrink as a consequence of the investment. In short: The firms understand that the long-run effect of their investment may be that there will be less tax revenue to recycle in the future. If spillovers between the firms are large, the aggregate effect on government revenue of investments from one single firm may be substantial, even if the firm is small compared to the industry. Even though the firm-level transfers are not contingent on individual investment levels, recycling will weaken the incentives to invest in the green technology.

It is well understood that revenue recycling with individual transfers that are contingent on behavior, for example based on consumption or production levels of the recipients, may impede the effect of carbon taxation. However, if revenue is recycled by use of lump-sum transfers, the intuitive prediction is that the recycling scheme will not affect the response in aggregate emissions to the carbon tax. It is this conclusion that is challenged by the findings of this paper. In industries with substantial knowledge spillovers between firms, revenue recycling can impede, and in some cases even completely eliminate, development of new green technology. The problem can arise even when the transfers to each firm are not directly linked to their investment in green technologies, and it can arise regardless of the size of the industry or the number of firms. An obvious implication of the findings is that policy makers should avoid revenue recycling in sectors with large knowledge spillovers. However, it is possible also to counteract the problem, for example by covering multiple sectors in the same revenue recycling scheme. By doing that, one can limit the effect on overall revenue of investments by individual firms, assuming knowledge spillovers are smaller across sectors.

The distributional effects of carbon tax revenue recycling are studied by, among others, Bourgeois et al. (2021), who focus on potential schemes for the French economy, Cronin et al. (2019), with a focus on the US, and Beck et al. (2015), who evaluate the implemented scheme in British Columbia.

Montero (2008) shows how repayment of revenue from pollution taxation can play a key role in inducing privately informed firms to truthfully report their abatement costs, enabling the government to implement first-best abatement.⁹ In the current paper, the government is assumed to be fully informed about abatement costs. However, combining the technological spillovers introduced in this paper with the information revelation problem studied by Montero (2008) would introduce a trade-off for the government, where repayment would induce information revelation, but also weaken incentives to invest in technology.

Furthermore, several papers investigate variations of transport-sector revenue recycling schemes; see for example Kessler et al. (2023), Durrmeyer (2022), Durrmeyer & Samano (2018) and d'Haultfoeuille et al. (2014) for studies of the French transport sector feebate system, and Adamou et al. (2014) for simulation of potential systems for Germany.

The current paper contributes to the literature on recycling of revenue from taxation of pollution by highlighting the problem that can arise in the long run if there are knowledge spillovers between firms in the industry. The relation between development of new green technology and direct recycling of revenue from carbon taxation towards industries with firm-to-firm knowledge spillovers has, to my knowledge, not been studied, neither theoretically nor empirically.

The paper further contributes to the broader literature on the determinants of green technological development and on optimal climate policy. Important recent contributions are Lemoine (2024), Blanchard et al. (2023), Stern & Valero (2021) and Hart (2019).¹⁰ Furthermore, Newell et al. (1999), Popp (2002), Acemoglu et al. (2012) and Aghion et al. (2016) are key contributions highlighting the relationship between fossil energy prices and green technological development, shedding further light on the effects of carbon pricing. The current paper illustrates that revenue recycling can weaken the relationship between firms are important.

The paper is organized as follows. The model is presented in Section 2, followed by results in Section 3. The first best is established as a benchmark case in Section 3.1. In section 3.2, I study the effects of revenue recycling in a setting where the government is fully informed about firm-level green technology investments. In Section 3.3, these effects are studied in a setting with a less well-informed government. Finally, I conclude in Section 4.

⁹Montero (2008) also provides a thorough discussion of firms' incentives to collude when revenue is recycled. ¹⁰See also Calel & Dechezleprêtre (2016), Golosov et al. (2014), Popp et al. (2010) and Popp (2019).

2 Model

The model can be extended in several directions, but to make the main mechanisms as transparent as possible, I keep the framework simple. There are N identical firms. Firm i uses fossil energy, e_i , in production, and their profits are represented by $\pi(e_i)$, with $\pi'(\cdot) > 0$, $\pi'' < 0$. Each firm can invest in a green technology, modeled as follows: By investing at a cost $c(s_i)$, with $c'(\cdot) > 0$ and c'' > 0, firm i can use s_i units of energy without emissions. Investment in s_i can thus be thought of as investing in technology for either abatement or a clean energy alternative.

There are technology spillovers between firms: A share $\alpha \in [0, 1]$ of the technology developed by firm j can be used to abate emissions also by all other firms. The net emissions from firm i, x_i , are therefore given by:¹¹

$$x_i = e_i - s_i - \alpha \sum_{j \neq i} s_j. \tag{1}$$

The real-world counterpart of the green technologies represented by s_i in the model will be different across industries. In fossil electricity production, new abatement technologies can, for example, be related to carbon capture and storage, while in the transport sector, more energy efficient fossil engines, or improvement of hybrid technologies, are relevant examples. Technology investments can be related to pure innovation, or they can be related to the use of known technologies in new areas. Although some of these investments can lead to patented innovations, not all knowledge can be patented. It is not unlikely that firms within the same industries will to some extent be able to take advantage of new knowledge and technology developed in other firms. It is such benefits I wish to capture in the spillovers included in the model.¹²

The extent of spillovers, and the firms' ability to protect their own technology development will, in the real world, vary across sectors and technologies. The findings of ? indicate that the

¹¹Assume throughout that all firms have positive emissions in equilibrium, i.e., that $e_i - \sum_j s_j > 0$ for all *i*.

 $^{^{12}}$ For technologies that can be protected to some extent, it is also possible to model a market for innovations within industries. Patenting and markets for innovations would clearly create an incentive to invest in the technology in the model, also in the absence of policy. However, as long as not all innovations can be protected and traded, the mechanisms at play in the model will still be relevant.

social value of RD in US firms is at least twice the private value, due to between-firm spillovers. In a more recent contribution, Rahko & Alola (2024) investigate effects of across-border spillovers on emissions, and their findings, again, indicate that knowledge and technology spillovers are affecting aggregate emission levels, as they find substantial between-country spillovers.

Timing. In the short run, the firms can adjust only their energy use, e_i , while, in the long run, they can also adjust their investment in the green technology.

Welfare. The aggregate damage from emissions is assumed to be linear, with marginal damage d, so that welfare is given by:

$$W \equiv \sum_{j} \left(\pi(e_j) - c(s_j) \right) - d \sum_{j} x_j.$$
⁽²⁾

Policy. A policy maker that can observe emissions and investments in green technology can implement an emissions tax, τ , per unit of emissions, and an investment subsidy, ψ , per unit of investment in the green technology. In addition, I will allow the policy maker to transfer a share, $\gamma \in [0, 1]$, of their net revenue to the firms through a flat transfer of T per firm, with:

$$T = \frac{1}{n}\gamma \cdot total \ revenue \ . \tag{3}$$

3 Results

3.1 First Best

Before presenting the equilibrium, I establish the welfare-maximizing allocation as a benchmark. W is maximized if the following two conditions hold for all i:

$$\pi'(e_i^{FB}) = d,\tag{4}$$

$$c'(s_i^{FB}) = d(1 + (n-1)\alpha).$$
(5)

The first best can be implemented in the long-run equilibrium by a pigouvian tax, $\tau^{FB} = d$, and a subsidy reflecting the extent of technology spillovers: $\psi^{FB} = d(n-1)\alpha$ (see Appendix A.1).

3.2 Revenue Recycling under Full Information

Now consider the case where the government is constrained to redistribute a share, γ , of the revenue from carbon taxation, net of spending on the subsidy, as an equal transfer to each firm.^{13,14}

Firm *i*, facing τ , ψ and *T*, will maximize:

$$\Pi \equiv \pi(e_i) - c(s_i) - \tau \left(e_i - s_i - \alpha \sum_{j \neq i} s_j \right) + \psi s_i + T, \tag{6}$$

given that

$$T = \frac{1}{n} \gamma \left[\tau \sum_{k} \left(e_k - s_k - \alpha \sum_{j \neq k} s_j \right) - \psi \sum_{k} s_k \right].$$
(7)

In the short-run equilibrium, the firm will optimize only with respect to e_i , and the firstorder condition requires:¹⁵

$$\pi'(e_i) = \tau \left(1 - \frac{1}{n}\gamma\right). \tag{8}$$

Recycling of revenue through T affects equilibrium behavior only by lowering the effective tax rate somewhat for a given τ , and this effect disappears if n is large.

In the long-run equilibrium, the firm optimizes with respect to both e_i and s_i , and the two first-order conditions are given by Equation (8) and:¹⁶

$$c'(s_i) = (\tau + \psi) \left(1 - \frac{1}{n} \gamma \right) - \frac{n-1}{n} \gamma \alpha \tau.$$
(9)

Proposition 1 For any set of policies, τ and ψ , and for any number of firms, n, increased revenue recycling will lower equilibrium investments in the green technology in the long-run equilibrium:

$$\frac{ds_i}{d\gamma} < 0 \ , \ \forall i. \tag{10}$$

¹³The main results carry over to the case where the gross revenue from carbon taxation is recycled.

¹⁴Because the main focus of the paper is on recycling of revenue from carbon taxation, I will assume throughout that the revenue from taxation, net of spending on the investment subsidy, is non-negative.

¹⁵Assume $\pi'(0)$ is sufficiently large for the sufficient conditions for interior maximum to hold.

¹⁶The sufficient conditions for interior maximum hold, as $\pi'' < 0$ and c'' > 0.

See Appendix A.2 for the proof.

When there are technological spillovers, green-technology investments in an individual firm will affect emissions not only from that firm itself, but also from other firms in the industry, because the other firms can take advantage of the knowledge and technology developed in the investing firm. Therefore, investments in an individual firm will lower not only their own tax payments, but also the tax payments of all firms in the industry. And because the investing firm receives a transfer that is a share of the total public revenue, investment will decrease the equilibrium transfer the firm receives. If the technology spillovers are substantial, investing in the green technology can have a non-negligible negative impact on the equilibrium transfer the firm receives, even if firm i gets only a small share of the total tax revenue. The incentive created by the carbon tax to invest in technology will therefore be weakened when tax revenue is recycled. When technological spillovers are important, i.e., when α is larger, the disincentive to invest created by revenue recycling becomes larger.

While the direct effect of recycling, which is to lower the effective tax and subsidy relative to the implemented τ and ψ , is diminishing as $n \to \infty$, the disincentive to invest created by the repayment through the spillover is not. Therefore, the result in Proposition 1 holds even if the number of firms is large and each firm is small relative to the industry as a whole.

A key implication of Proposition 1 is that in sectors where technological change is crucial for emission reduction, recycling of revenue may impede an important part of the effect of carbon pricing.

Note that the mechanisms behind the result in Proposition 1 can also be at play for schemes where revenue is recycled towards households or consumers. For example, revenue recycling schemes in the transport sector can be designed with transfers paid out as subsidies for the purchase or use of low-emission vehicles. Typically, some share of these transfers will, in equilibrium, end up with car manufacturers. If there are knowledge spillovers between firms in this sector, and the firms produce both high- and low-emission cars, revenue recycling can impede incentives to invest in the development of new low-emission technologies for the reasons described above.

Proposition 2 For any set of policies, τ and ψ , and for any number of firms, n, if there is

full technological spillover and the entire net revenue is recycled, i.e., $\alpha = \gamma = 1$, the incentive created by the carbon tax to invest in green technology is completely eliminated:

$$\frac{ds_i}{d\tau} = 0 \ , \ \forall i. \tag{11}$$

See Appendix A.2 for the proof.

Proposition 2 states that the incentive created by the carbon tax to invest in the green technology will be completely eliminated in the special case where technology development is a public good in the sector ($\alpha = 1$) and there is full revenue recycling ($\gamma = 1$). This is the case regardless of the number of firms in the sector. The intuition is, as described above: The result of investment in new green technology is that emissions fall across the industry. Although this is, of course, a good outcome for society, it reduces the transfer for the investing firm. When $\alpha = \gamma = 1$, the resulting disincentive to invest exactly balances out the incentive to invest created by the carbon tax in the first place.

In the short run, revenue recycling will affect firm behavior only by slightly reducing the effective tax rate for a given τ , and this effect will diminish if n is large. Regardless of n, the shortrun effect can always be counteracted by increasing τ , and the first best can be implemented. The effect of recycling on investment in green technology in the long-run equilibrium, as described in Propositions 1 and 2, however, does not diminish as n gets larger. The reason is that although having a large number of firms means that each firm gets a small share of the recycled revenue, each firm's technology spills over to all other firms. An individual firm investing in green technology will lower not only their own emissions, but also those of the other firms in the industry, and these other firms' subsequent tax payments. Therefore, even for a large n, investment in green technology by an individual firm may substantially affect the transfer that firm receives in equilibrium.

Moreover, as is clear from Proposition 2, the disincentive to invest resulting from revenue recycling cannot necessarily be counteracted by increasing the tax, τ . In the extreme case with $\alpha = \gamma = 1, \tau$ will no longer affect investment, and increasing τ will therefore not alleviate the problem.

With full information on firm-level investments in the green technology, the policy maker

can, however, always implement the first best, despite the disincentive to invest created by revenue recycling. The first best can be implemented by adjusting the tax and the subsidy relative to the case with no recycling, as follows (see Appendix A.2):

$$\tau = \frac{d}{1 - \frac{1}{n}\gamma} \tag{12}$$

$$\psi = \frac{d}{1 - \frac{1}{n}\gamma} (n - 1)\alpha \left(1 + \frac{\gamma}{n - \gamma}\right).$$
(13)

The subsidy is increased to counteract the disincentive to invest created by the revenue recycling scheme. In Section 3.3, I analyze the case where the government is not fully informed about firm-level investments or firm-to-firm spillovers. In this case, the first best can no longer be implemented if the government is constrained to recycle revenue.

In the analysis above, it is assumed that firms are identical and that the technological spillover is the same between any set of firms. The model can, however, easily be extended to allow for heterogeneous firms and heterogeneous technology spillovers between them, as I illustrate in Appendix A.2. In a sector where only one or a few firms drive technological change, revenue recycling will weaken the crucial incentive that the carbon tax creates to invest in green technology, for these key firms. As in the basic model, the policy maker can still implement the first best. To implement first-best investment levels, the investment subsidy must be large enough to reflect the technological spillovers from each investment and counteract the the disincentive to invest created by the recycling transfer.

3.3 Revenue Recycling under Partial Information

In many real-world settings, investment subsidies, as described above, can be difficult to implement. It can be costly, or even impossible, to verify information on firm-level investments in specific technologies or on between-firm technological spillovers. Moreover, subsidization can be associated with costs that are not considered in this model, such as harmful rent-seeking activities, administrative costs, or tax distortions. In this section, I therefore consider the case where the policy maker cannot subsidize investments. The only policy instrument available is the emissions tax, τ , together with the flat transfer, T. Firm *i* will now maximize (6), given $\psi = 0$. The results presented in Propositions 1 and 2 carry over to this setting, as I show in Appendix A.3. If a larger share of revenue is recycled, equilibrium investments will be lower for a given tax, τ . And for full recycling and full spillovers, the tax will no longer incentivize investments. An extension to this last result arises when subsidies cannot be used:

Proposition 3 There will be no investments in green technology in equilibrium when all government revenue is recycled to the firms and there is full technological spillover, i.e., $\gamma = \alpha = 1$, and the only available policy instrument is an emissions tax:

$$s_i = 0 \quad for \quad \gamma = \alpha = 1, \quad when \quad \psi = 0 \quad for \quad any \ \tau.$$
 (14)

See Appendix A.3 for the proof.

When lack of information, or other obstacles, hinders the government from subsidizing firm-level investment in the green technology, the carbon tax is the only instrument that can incentivize investment. As a result, if the revenue recycling scheme eliminates the incentive to invest created by the tax, there will be no investment in equilibrium.

Proposition 4 When the policy maker cannot subsidize investments, the highest welfare will be obtained by a carbon tax above the pigouvian level, and with no revenue recycling:

$$\tau = d \frac{c'' - \pi'' \left(1 + (n-1)\alpha\right)}{c'' - \pi''} > d,$$
(15)

$$\gamma = 0. \tag{16}$$

See Appendix A.3 for the proof.

When the emissions tax is the only available policy instrument, the policy maker can no longer implement the first best if $\alpha > 0$, regardless of revenue recycling. However, because the emissions tax will incentivize green-technology investments, the optimal second-best policy entails setting the tax above the pigouvian level. Because the tax is the only instrument available to induce green-technology investment, recycling tax revenue, and thereby diminishing the incentive the tax creates for investment, will be welfare-deteriorating. The second-best policy therefore entails no revenue recycling.

4 Conclusions

A growing literature suggests that carbon tax revenue recycling, repaying public revenue directly to the firms or households targeted by a carbon tax, can be part of the solution for several challenges facing policy makers with ambitious climate policy goals. At the same time, development of new green technologies – technologies for emission abatement, energy efficiency and renewable energy generation – is key to reaching global climate targets. It is therefore crucial to understand how the design of climate policy, including revenue recycling schemes, affects incentives to invest in development of green technologies.

In this paper, I have applied a stylized model of firms making decisions about shortrun abatement of emissions and about long-run investments in new abatement technology, to illustrate that in the long run, carbon tax revenue recycling may impede incentives to invest in the new technology. The problem arises if there are technological spillovers between firms in the sense that development of new technology in one firm reduces the cost of abatement also in other firms. The reason the problem arises is that investment in the new technology in one firm – even if this firm is small relative to the industry – can substantially affect aggregate government revenues from carbon taxation if the technology development leads to higher abatement across the industry. If the investing firm expects to receive a share – even a small one – of this aggregate revenue, the firm will be more reluctant to invest in green technology development.

To avoid the problem illustrated in this paper, policy makers can avoid revenue recycling in sectors where there are large knowledge spillovers. However, it is also possible to counteract the problem by including different sectors in the same revenue recycling schemes. As long as technology spillovers are not substantial across sectors, the effect of investment on aggregate revenues to be recycled in each individual firm will get smaller. As a consequence, the disincentive to invest created by the recycling scheme will also get smaller.

The extent of spillovers between firms when they invest in green technology is likely to vary across firms and industries. The mechanisms pointed out in this paper rely completely on such spillovers. Future research should therefore investigate the empirical relevance of the mechanisms that are illustrated in this paper for industries where revenue recycling schemes are considered.

A Appendix

A.1 First best

In the long-run equilibrium, it follows from the first-order conditions, (8) and (9), and the conditions for welfare maximization, (4) and (5), that the first best can be implemented by $\gamma = 0, \tau = d$ and $\psi = d(n-1)\alpha$.

A.2 Revenue Recycling under Full Information

Proof of Proposition 1. It follows from the first-order condition in Equation (9) that, for any τ and ψ , investments are decreasing in γ :

$$\frac{ds_i}{d\gamma} = -\frac{1}{c''} \left[\frac{1}{n} \psi + \frac{1}{n} \tau (1 + (n-1)\alpha) \right] < 0 \text{ for any } n.$$

$$\tag{17}$$

The disincentive to invest created by the revenue recycling scheme does not diminish as $n \to \infty$:

$$\lim_{n \to \infty} \frac{ds_i}{d\gamma} = -\frac{1}{c''} \alpha \tau < 0.$$
(18)

Proof of Proposition 2. Inserting $\gamma = \alpha = 1$ in the first-order condition in Equation (9) gives:

$$c_i'(s_i) = \psi\left(1 - \frac{1}{n}\right). \tag{19}$$

It follows that s_i is no longer affected by τ .

Optimal constrained policy. The welfare-maximizing policy under the constraint that a share γ of net revenue is recycled, represented by Equations (15) and (16), follows directly from the first-order conditions of the firm (Equations (8) and (9)) and the conditions for first best (Equations (4) and (5)).

Firm and spillover heterogeneity. To allow for heterogeneity across firms, let $\pi_i(\cdot)$ and $c_i(\cdot)$ represent profits and investment costs, respectively, for firm *i*. Furthermore, let $\alpha_{ij} \in [0, 1]$

represent the technological spillover from firm i to firm j, so that:

$$x_i = e_i - s_i - \sum_{j \neq i} \alpha_{ji} s_j.$$
⁽²⁰⁾

The first best now requires investments to differ across firms, according to:

$$c_i'(s_i) = d\left(1 + \sum_{j \neq i} \alpha_{ij}\right),\tag{21}$$

and the welfare-maximizing allocation can be implemented by a firm-specific subsidy of $\psi_i = d \sum_{j \neq i} \alpha_{ij}$ on top of the pigouvian tax, $\tau = d$, for $\gamma = 0$.

For a positive transfer, $\gamma > 0$, the firm will maximize Π , (Equation (6)), given an individual subsidy ψ_i and a transfer of:

$$T = \frac{1}{n}\gamma \left[\tau \sum_{k} \left(e_k - s_k - \sum_{j \neq k} \alpha_{jk} s_j\right) - \sum_{k} \psi_k s_k\right].$$
 (22)

Energy use and investment are determined by the following first-order conditions:

$$\pi'(e_i) = \tau \left(1 - \frac{1}{n}\gamma\right) \tag{23}$$

$$c'(s_i) = (\tau + \psi_i) \left(1 - \frac{1}{n}\gamma\right) - \tau \frac{1}{n}\gamma \sum_{j \neq i} \alpha_{ij}.$$
(24)

Both Proposition 1 and Proposition 2 carry over to this setting, because the first-order condition in Equation (24) implies

$$\frac{ds_i}{d\gamma} = -\frac{1}{c''} \left[\frac{1}{n} (\tau + \psi_i) + \frac{1}{n} \tau \sum_{j \neq i} \alpha_{ij} \right] < 0 \text{ for any } n,$$
(25)

and that $ds_i/d\tau = 0$ for any firm with $\alpha_{ij} = 1$ for all $j \neq i$, if $\gamma = 1$.

A.3 Revenue Recycling under Partial Information

When the tax, τ , is the only policy instrument available, firm *i* will maximize (6) given $\psi = 0$. Propositions 1 and 2 carry over directly to this setting, because Equation (9) then implies $c'(s_i) = 0$ for any τ if $\gamma = \alpha = 1$, while

$$\frac{ds_i}{d\gamma} = -\tau \frac{1}{n} \left(1 + (n-1)\alpha \right) < 0.$$
(26)

Proof of Proposition 3. The result follows because the first-order condition in (9) now implies $c'(s_i) = 0$ for any τ if $\gamma = \alpha = 1$, when $\psi = 0$.

Proof of Proposition 4. From Equations (8) and (9), we can define energy use and investment as functions of τ and γ , given $\psi = 0$, $e_i(\tau, \gamma)$ and $s_i(\tau, \gamma)$, with:

$$\frac{\partial e_i}{\partial \tau} = \frac{1 - \frac{1}{n}\gamma}{\pi''} < 0 \qquad \qquad \frac{\partial e_i}{\partial \gamma} = -\frac{\frac{1}{n}\tau}{\pi''} > 0, \tag{27}$$

$$\frac{\partial s_i}{\partial \tau} = \frac{1 - \frac{1}{n}\gamma\left(1 + (n-1)\alpha\right)}{c''} < 0 \qquad \qquad \frac{\partial s_i}{\partial \gamma} = -\frac{\frac{1}{n}\tau\left(1 + (n-1)\alpha\right)}{c''} > 0.$$
(28)

The constrained policy maker then solves:

$$\max_{\tau,\gamma} \sum_{i} \left\{ \pi \left(e_i(\tau,\gamma) \right) - c \left(s_i(\tau,\gamma) \right) - d \left(e_i(\tau,\gamma) - s_i(\tau,\gamma) - \alpha \sum_{j \neq i} (s_j(\tau,\gamma)) \right) \right\}.$$
(29)

This problem is solved by (15) and (16). To see this, define the value of a marginal increase in each of the two policy variables as:

$$M_{\tau} = \frac{\partial e_i}{\partial \tau} \left(\pi'(e_i) - d \right) - \frac{\partial s_i}{\partial \tau} \left(c'(s_i) - d(1 + (n-1)\alpha) \right), \tag{30}$$

$$M_{\gamma} = \frac{\partial e_i}{\partial \gamma} \left(\pi'(e_i) - d \right) - \frac{\partial s_i}{\partial \gamma} \left(c'(s_i) - d(1 + (n-1)\alpha) \right). \tag{31}$$

First, note that an interior solution for both τ and γ is not possible, because $M_{\tau} = M_{\gamma} = 0$ would imply both Equation (15) and $\tau = d/(1 - \frac{\gamma}{n})$. Next, we see that $\tau = 0$ implies $M_{\tau} > 0$, while $\tau \to \infty$ implies $M_{\tau} < 0$, and can conclude that we must have an interior solution for τ (implying $M_{\tau} = 0$, solved by (15)). Inserting for $M_{\tau} = 0$ in (31) yields

$$M_{\gamma} = \tau \frac{1}{n\pi''} \left(\tau \left(1 - \frac{1}{n}\gamma \right) - d \right) \frac{\alpha(n-1)}{1 - \frac{1}{n}\gamma(1 + (n-1)\alpha)}.$$
(32)

From (32), we see that $M_{\gamma} < 0$ when $\gamma = 1$ when (15) holds, so we can conclude that (15) and (16) solve the government's problem.

References

- Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American Economic Review*, 102(1), 131-66.
- Adamou, A., Clerides, S., & Zachariadis, T. (2014). Welfare implications of car feebates: A simulation analysis. The Economic Journal, 124 (578), F420–F443.
- Aghion, P., Dechezleprêtre, A., Hémous, D., Martin, R., & Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *Journal* of Political Economy, 124(1), 1-51.
- Aghion, P., & Jaravel, X. (2015). Knowledge spillovers, innovation and growth. The Economic Journal, 125(583), 533–573.
- Barrez, J. (2024). Public acceptability of carbon pricing: unravelling the impact of revenue recycling. *Climate Policy*, $\theta(0)$, 1–23.
- Beck, M., Rivers, N., Wigle, R., & Yonezawa, H. (2015). Carbon tax and revenue recycling: Impacts on households in British Columbia. *Resource and Energy Economics*, 41, 40–69.
- Beiser-McGrath, L. F., & Bernauer, T. (2019). Could revenue recycling make effective carbon taxation politically feasible? *Science Advances*, 5(9), eaax3323.
- Blanchard, O., Gollier, C., & Tirole, J. (2023). The portfolio of economic policies needed to fight climate change. *Annual Review of Economics*, 15(1), 689–722.
- Bloom, N., Schankerman, M., & Van Reenen, J. (2013). Identifying technology spillovers and product market rivalry. *Econometrica*, 81(4), 1347–1393.
- Böhringer, C., Fischer, C., & Rivers, N. (2024). Rebating revenues from unilateral emissions pricing. CESifo Working Paper No. 11376.
- Bourgeois, C., Giraudet, L.-G., & Quirion, P. (2021). Lump-sum vs. energy-efficiency subsidy recycling of carbon tax revenue in the residential sector: A French assessment. *Ecological Economics*, 184, 107006.

- Calel, R., & Dechezleprêtre, A. (2016). Environmental policy and directed technological change:
 Evidence from the European carbon market. *Review of Economics and Statistics*, 98(1), 173–191.
- Carattini, S., Carvalho, M., & Fankhauser, S. (2018). Overcoming public resistance to carbon taxes. Wiley Interdisciplinary Reviews: Climate Change, 9(5), e531.
- Cronin, J. A., Fullerton, D., & Sexton, S. (2019). Vertical and horizontal redistributions from a carbon tax and rebate. *Journal of the Association of Environmental and Resource Economists*, 6(S1), S169–S208.
- Dabla-Norris, E., Khalid, S., Magistretti, G., & Sollaci, A. (2023). Public support for climate change mitigation policies: A cross country survey. *IMF Working Paper No. 2023/223*.
- d'Haultfoeuille, X., Givord, P., & Boutin, X. (2014). The environmental effect of green taxation: The case of the French bonus/malus. *The Economic Journal*, 124 (578), F444–F480.
- Douenne, T., & Fabre, A. (2022). Yellow vests, pessimistic beliefs, and carbon tax aversion. American Economic Journal: Economic Policy, 14(1), 81–110.
- Dugstad, A., Grimsrud, K. M., & Lindhjem, H. (2024). Carbon pricing acceptance the role of revenue recycling among households and companies in Norway. *Climate Policy*, 1–16.
- Durrmeyer, I. (2022). Winners and losers: The distributional effects of the french feebate on the automobile market. *The Economic Journal*, 132(644), 1414–1448.
- Durrmeyer, I., & Samano, M. (2018). To rebate or not to rebate: Fuel economy standards versus feebates. *The Economic Journal*, 128(616), 3076–3116.
- Fischer, C., & Newell, R. G. (2008). Environmental and technology policies for climate mitigation. Journal of Environmental Economics and Management, 55(2), 142–162.
- Golosov, M., Hassler, J., Krusell, P., & Tsyvinski, A. (2014). Optimal taxes on fossil fuel in general equilibrium. *Econometrica*, 82(1), 41–88.

- Hart, R. (2019). To everything there is a season: Carbon pricing, research subsidies, and the transition to fossil-free energy. Journal of the Association of Environmental and Resource Economists, 6(2), 349–389.
- Jaffe, A. B. (1986). Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits, and market value. *American Economic Review*, 76(5), 984-1001.
- Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics*, 54(2-3), 164–174.
- Jones, C. I., & Williams, J. C. (1998). Measuring the social return to R&D. The Quarterly Journal of Economics, 113(4), 1119–1135.
- Kessler, L., Morvillier, F., Perrier, Q., & Rucheton, K. (2023). An ex-ante evaluation of the French car feebate. *Energy Policy*, 173, 113335.
- Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R., & Stern, N. (2018). Making carbon pricing work for citizens. *Nature Climate Change*, 8(8), 669–677.
- Lemoine, D. (2024). Innovation-led transitions in energy supply. American Economic Journal: Macroeconomics, 16(1), 29–65.
- Mildenberger, M., Lachapelle, E., Harrison, K., & Stadelmann-Steffen, I. (2022). Limited impacts of carbon tax rebate programmes on public support for carbon pricing. *Nature Climate Change*, 12(2), 141–147.
- Montero, J.-P. (2008). A simple auction mechanism for the optimal allocation of the commons. American Economic Review, 98(1), 496–518.
- Muth, D. (2023). Pathways to stringent carbon pricing: Configurations of political economy conditions and revenue recycling strategies. A comparison of thirty national level policies. *Ecological Economics*, 214, 107995.
- Newell, R. G., Jaffe, A. B., & Stavins, R. N. (1999). The induced innovation hypothesis and energy-saving technological change. *Quarterly Journal of Economics*, 114(3).

- Pearce, D. (1991). The role of carbon taxes in adjusting to global warming. The Economic Journal, 101(407), 938–948.
- Popp, D. (2002). Induced innovation and energy prices. American Economic Review, 92(1), 160-180.
- Popp, D. (2019). Environmental policy and innovation: A decade of research. International Review of Environmental and Resource Economics, 13(3-4), 265-337.
- Popp, D., Newell, R. G., & Jaffe, A. B. (2010). Energy, the environment, and technological change. Handbook of the Economics of Innovation, 2, 873–937.
- Rahko, J., & Alola, A. A. (2024). The effects of climate change technology spillovers on carbon emissions across European countries. *Journal of Environmental Management*, 370, 122972.
- Sen, S., & Vollebergh, H. (2018). The effectiveness of taxing the carbon content of energy consumption. Journal of Environmental Economics and Management, 92, 74–99.
- Sommer, S., Mattauch, L., & Pahle, M. (2022). Supporting carbon taxes: The role of fairness. Ecological Economics, 195, 107359.
- Stern, N., & Valero, A. (2021). Innovation, growth and the transition to net-zero emissions. Research Policy, 50(9), 104293.
- Timilsina, G. R. (2022). Carbon taxes. Journal of Economic Literature, 60(4), 1456–1502.
- Yamazaki, A. (2017). Jobs and climate policy: Evidence from British Columbia's revenueneutral carbon tax. Journal of Environmental Economics and Management, 83, 197–216.
- Équiterre. (2020). The road ahead to low-carbon mobility A feebate system for Canada's light-duty vehicle segment. *Technical report*. doi: 20.500.12592/5nc1tw