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THE ROLE OF LARGE FIRMS, COMMON OWNERSHIP, AND GOVERNMENTS

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Strategic Commitments to Decarbonize: The Role of Large Firms, Common Ownership, and Governments
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ABSTRACT

We study how government policies and corporate commitments to decarbonize interact under two externalities: environmental damages and green innovation spillovers. Unconstrained carbon taxes and innovation subsidies could achieve first-best outcomes, but when government policies face constraints, commitments by large firms and institutional investors can serve as profit-driven coordination devices that spur green innovation and technology adoption, and thereby reduce overall transition costs. Firm commitments also enhance government policy credibility by lowering the need for high future carbon taxes. Our empirical evidence confirms that firm size and green common ownership drive Net Zero commitments and decarbonization investments.

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1 Introduction

The 2015 Paris Agreement, agreed at the COP21 (21^{st} annual United Nations climate meeting), marked a turning point in climate negotiations, with nearly 200 nations committing to achieve "Net Zero" greenhouse gas emissions by 2050. Yet these pledges lack specific enforcement mechanisms. As governments struggle to implement credible climate policies, an unexpected group has emerged as catalysts for change: large corporations and institutional investors. Figure 1, based on global data from the Science Based Targets initiative (SBTi), shows that over 1,200 firms had made Net Zero commitments between 2016 and 2023.

This surge in private sector climate commitments raises fundamental questions: What role can these commitments play in accelerating decarbonization? Why would profit-seeking firms and investors make such commitments? And how do these private initiatives interact with government incentives for decarbonization and green innovation?

In this paper, we show that even profit-motivated large firms and institutional investors can accelerate the green transition when policy instruments are constrained. We model firms' choices over production, emissions, and green innovation or technology adoption in an economy with two key market failures: environmental damages from carbon emissions and technological spillovers where social returns to green innovation exceed private returns. This dual externality has been highlighted as central to the green transition challenge (Acemoglu et al., 2012, 2016).

Our main result is that when governments face constraints on green innovation subsidies, large firms and common ownership (i.e., coalitions of firms held by overlapping large institutional investors) can serve as catalysts for the green transition through purely profit-maximizing behavior, without sacrificing returns for environmental benefits. In turn, these private commitments reduce pressure for future carbon taxes, enhancing the credibility of government climate policies.

Consider first the case with only an environmental externality. Assuming that carbon emissions by firms can be measured and Pigouvian taxes designed and implemented around them, the planner can achieve a socially optimal transition to the first-best allocation simply through a judicious design of these taxes. In particular, there is no need for commitments by the government (the entity that can implement these taxes) or the firms, in that commitments do not serve any purpose over and above the efficacy of these taxes. The private sector is forward-looking in our model and anticipates that future governments will have to set high carbon taxes if emissions remain high. This rational expectation is sufficient

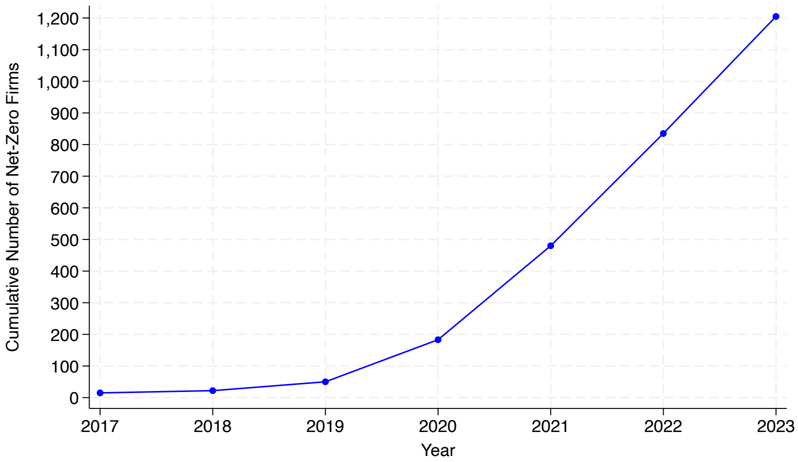

Figure 1: Total Net Zero firm commitments.

on its own not only to induce the optimal production plans but also the right incentives to innovate. Introducing a technological externality in innovation to the basic setup does not necessarily alter this insight. In particular, as in the seminal work of Acemoglu et al. (2012), if two separate Pigouvian instruments such as carbon taxes and green innovation subsidies are available to address the two respective externalities, then again the socially optimal transition can be decentralized without any commitment by governments or firms.

This benchmark result on the irrelevance of commitments then helps understand why Net Zero commitments might matter in practice. The assumption that the space of policy instruments is rich enough to address the multitude of externalities in managing climate change can be considered a mere theoretical possibility. Different countries may face different constraints. For instance, the policy at present in Europe is focused more on measuring total emissions and taxing them, rather than measuring green innovation that lowers emission intensity and incentivizing it; the opposite holds in the U.S., with the Inflation Reduction Act of 2022 introducing substantial green innovation subsidies (aimed at reducing emission intensity) but no carbon pricing. These are two extreme cases, and in practice every country may face some positive, but asymmetric, constraint on each instrument.

In the second-best environment featuring constrained public policies, we examine the role of commitments by the private sector in fostering efficient decarbonization. Firm commitments are defined as “over-investments” in green innovation relative to a standard decentralized equilibrium, as innovation is the only credible way firms can ensure reaching low emissions. If firms are all small (i.e., atomistic), then no individual firm will make such commitments. Commitments are only value-enhancing if they can change the firm's equilibrium payoff, and small firms do not (anticipate that they can) affect the equilibrium.

However, if some firms can coordinate their efforts towards emission reduction, then these firms recognize that if they can act as "Stackelberg leaders" and provide binding commitments to Net Zero, then it would imply a transition path that would also incentivize all other firms to innovate. Specifically, given the innovation externality in our model, commitments by large firms to decarbonize by "over-investing" in green innovations would reduce the rationally-anticipated marginal cost of innovation by small firms, spurring green innovations throughout the economy. This would in turn produce in equilibrium an aggregate outcome with lower carbon tax bills for all firms, including for those making the commitments in the first place. This description makes clear that the firms making commitments must be acting non-atomistically, in the sense that they realize their actions can shift the equilibrium. This can take the form of commitments by "large" firms, but also by "green common ownership", i.e., coalitions of firms owned by large institutional investors belonging to a common climate alliance, taking into account positive spillovers in green innovation at the portfolio level.

We provide evidence (in Section 2) that this is indeed the case. Large firms in both the US and elsewhere have made (earlier) Net Zero commitments and undertaken (earlier) decarbonization investments. This is the case also for firms in the US owned more by large institutional investors (as reported in 13F SEC filings) who have themselves made Net Zero commitments. While the literature on common ownership reviewed below has mostly emphasized potential social costs due to anti-competitive behavior, our model highlights a bright side of common ownership in the presence of externalities in green innovation. In this sense, large firms and institutional investors play a role in climate change management that resembles the role of the government (or the social planner) in internalizing the benefits from technological spillovers. In the limit of a very large coalition of firm committers, the private sector can replicate the first-best allocation as firm commitments fully substitute for the lack of green innovation subsidies.

Note that we always assume that the firms making commitments are *purely profit-maximizing* and do not value emission reduction per se (e.g., through investors' environmental mandates or worker preferences). The only reason these firms commit is to ultimately reduce their carbon tax burden. This carbon tax-saving motive also highlights an important asymmetry in terms of constrained public policies. We show that firm commitments have large welfare benefits in countries with carbon taxes but constrained innovation subsidies, because taxes are where firms stand to save the most by committing. By contrast, firm commitments do not improve welfare as much when innovation subsidies are available unconstrained but carbon taxes are constrained.

We then turn to government commitments and how they interact with firm commitments. In the case of governments, we define commitments as announcements of future carbon taxes. The reason governments may want to make strong commitments is that the anticipation of a carbon tax above and beyond the social cost of carbon stimulates ex-ante green innovation by firms seeking to reduce their future carbon tax bill. Therefore promising a high carbon tax acts as an imperfect substitute for any missing green innovation subsidy. However, a carbon tax exceeding the social cost of carbon will turn out to be time-inconsistent ex post, once green technology investments have been sunk, and the future government will be tempted to lower the carbon tax back to the social cost of carbon.

We model the credibility of government policies by introducing a cost of reneging on previous commitments, which creates some limited commitment ability. We find that in general, when green innovation subsidies are constrained, governments will optimally promise a carbon tax above the social cost of carbon, and promise higher carbon taxes as their commitment ability increases. The key result is that *firm commitments improve government credibility*. The reason governments make commitments is to provide ex-ante incentives for green innovation when the private sector fails to internalize technological externalities. Firm commitments perform the same function, and therefore stronger firm commitments (for instance, when firms are large or institutional investors own a large fraction of firms) reduce the need of the government to promise high future carbon taxes, thereby making the government's promises more credible. In other words, in a world where government commitments to climate policies are likely to be weak, large firms and common ownership emerge as being paramount in shepherding the green transition.

Related literature

The literature on climate change policy highlights two key mechanisms for driving decarbonization: carbon pricing to internalize environmental damages, and directed innovation to accelerate the transition to clean technologies. Pioneering work by Nordhaus, developed over several decades and summarized in Nordhaus (2017), established the integrated assessment framework for analyzing optimal climate policy by combining economic growth, emissions, and climate dynamics.

A second crucial strand emerged from Acemoglu et al. (2012) and Acemoglu et al. (2016), showing that both carbon pricing and innovation policy are typically needed for efficient decarbonization. Recent empirical work sheds some light on the appropriate policy mix. Cohen, Gurun and Nguyen (2020) infer that innovation subsidies could be efficient for innovation incentives, but Bolton, Kacperczyk and Wiedemann (2023) argue that green innovation alone, without carbon pricing, fails to reduce emissions. These findings reinforce the theoretical argument for policy complementarity.

Our model is consistent with this literature in requiring *both* carbon taxes and innovation subsidies for efficiency, but assumes there are policy limitations in its attainment and focuses in such a setting on the role of firm commitments. Acemoglu and Rafey (2023) argue that under lack of government commitment, the anticipation of geoengineering breakthroughs and lower future carbon taxes undermines incentives to switch to green technology. Dávila and Walther (2023) studies corrective policies with imperfect instruments, focusing on how available instruments can be used to partially substitute for missing ones, as in our special case without firm commitments in Section 5; we then add firm commitments as a key alternative.

In this regard, López and Vives (2019) show theoretically that common ownership can lead to internalization of rivals' profits by firms, which leads to more efficient investments in cost-reducing R&D investments when innovation spillovers are sufficiently high.[1] Bloom, Schankerman and Van Reenen (2013) find sizeable spillovers, with social returns to R&D at least twice as high as private returns. Antón et al. (2021) also posit such a potentially bright side to common ownership, and verify empirically that it is beneficial to innovation outcomes (measured as increase in citation-weighted patents) when technological spillovers (proximity in patent space) across firms are stronger relative to product-market spillovers (proximity in product market space).[2]

In the legal scholarship and closer to the climate-change application, Condon (2020) argues conceptually, as we derive theoretically, that diversified common-owner investors should rationally be motivated to internalize intra-portfolio negative externalities, and that this portfolio perspective can explain the increasing climate-change related activism of institutional investors.[3] More broadly, a growing empirical (e.g., Dimson, Karakas and Li

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[1] Aghion, Van Reenen and Zingales (2013) study how institutional ownership affects innovation directly even without spillovers, for instance because institutional owners are able to better monitor firm managers and provide them insurance against the risks inherent to innovation.

[2] Lanteri and Rampini (2023) highlight a different asymmetry between small and large firms, unrelated to technological spillovers: it is easier for large firms to invest in cleaner but more expensive capital if they are less financially constrained.

[3] Relatedly, Gasparini, Haanaes and Tufano (2022) also explain how dealing with carbon emissions ef-

2015, Krueger et al. 2020, and the review by Kolasa and Sautner 2024) and theoretical (e.g., Broccardo, Hart and Zingales 2022, Oehmke and Opp 2024) literature on investor activism compares the impact of shareholder engagement mechanisms, i.e., "voice", with divestment or "exit" policies. In particular, Azar et al. (2021) documents how the "Big Three" (BlackRock, Vanguard, and State Street) successfully engages with firms in its portfolio to reduce emissions. While our model also shows how the benefits from private sector coordination through common ownership, the reason is *not* that large common investors simply act like social planners. Indeed, a crucial result of our analysis is that government interventions, in the form of carbon pricing or taxation, remain essential.

Finally, our results on the interaction of firm and government commitments are consistent with the empirical findings of Bolton and Kacperczyk (2021). When measured in terms of emissions objectives, firm and government commitments are substitutable as they document. However, our model also shows that they are complementary in terms of credibility. Firm commitments in our model make government commitments more credible, even though the government reduces its commitment; in fact, it is exactly because the government does not need to commit to such a high carbon tax when firms take on a larger share of the job that the government becomes more credible. To the best of our knowledge, this form of complementarity between firm and government commitments has not yet been tested in data.

2 Motivating Evidence

Following the 2015 Paris Agreement, firms began making significant Net Zero commitments. We analyze firm-level commitment data between 2016-2023, finding two key patterns: larger firms and those with greater institutional ownership by climate-focused investors are more likely to commit and undertake decarbonization investments.

We combine data from multiple sources to analyze firm commitment and decarbonization dynamics.

Net Zero commitments: Our primary source is the Science Based Targets initiative (SBTi), which provides regularly updated information on firms' progress toward Net Zero commitments. We downloaded the data of firms making Net Zero commitments from the

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fectively requires cooperation amongst companies across industries, but that in several jurisdictions "law might get in the way" by considering this as a form of anti-trust violation, and Miazad (2023) argues that Investor Climate Alliances (ICAs) provide a novel and necessary mechanism for climate governance via large, diversified investors ("universal owners"), rather than being an anti-trust concern.

SBTi website and complemented it with the "Net Zero Tracker" (https://zerotracker.net), on September 13, 2024. As of this date, 3,209 firms (1,371 firms with valid ISINs) had made Net Zero commitments in the full global sample.

Decarbonization investments and emission intensity: We obtain information about decarbonization investments and CO_2 emissions from the CDP (formerly Carbon Disclosure Project) survey. We follow Fuchs, Stroebel and Terstegge (2024) and extract firms' reported investments in emissions reduction technologies and initiatives. Our decarbonization investment measure is a dummy equal to one if a firm reports positive investments in emissions reduction between 2012 and 2022. We construct a firm's emission intensity as the sum of Scope 1 and Scope 2 emissions scaled by assets (for firms matched to Compustat, as explained below). Using this measure, we create an indicator variable equal to one if the average emission intensity in 2018-2022 was lower than the 2012-2017 average.

Firm characteristics: We merge the firm sample with Compustat (Global & North America) datasets by firms' ISINs to get information about firm size. For firms with missing or incorrect ISINs, we conduct fuzzy matching based on firm name, location, and region. In total, there are 45,649 firms in the Compustat sample. This process yields 1,205 Net Zero matched firms for our analysis. We measure firm size using its assets from Compustat as of the end of 2017. Based on assets, we classify firms into four size groups: "large" ($10 billion or more), "medium" ($2 billion to $10 billion), "small" ($250 million to $2 billion), and "micro-small" ($250 million or less). We also categorize firms into 10 industries following the Global Industry Classification Standards (GICS) 2-digit sectors.

Institutional ownership: Institutional ownership data comes from the United States Securities and Exchange Commission (SEC) 13F filings, following the methodology of Backus, Conlon and Sinkinson (2021). The 13F filings require all institutional investment managers with discretion over $100 million in assets under management to report their quarterly equity holdings. We use ownership data as of September 30, 2017. Investor holdings are calculated by aggregating the total market equity of their holdings.

Our baseline regression sample corresponds to 3,560 firms with complete data on both types of commitments, firm characteristics, and institutional ownership. Table A.1 in the Appendix provides summary statistics. The mean Net Zero commitment rate in our sample is 9%, while 19% of firms report decarbonization investments.

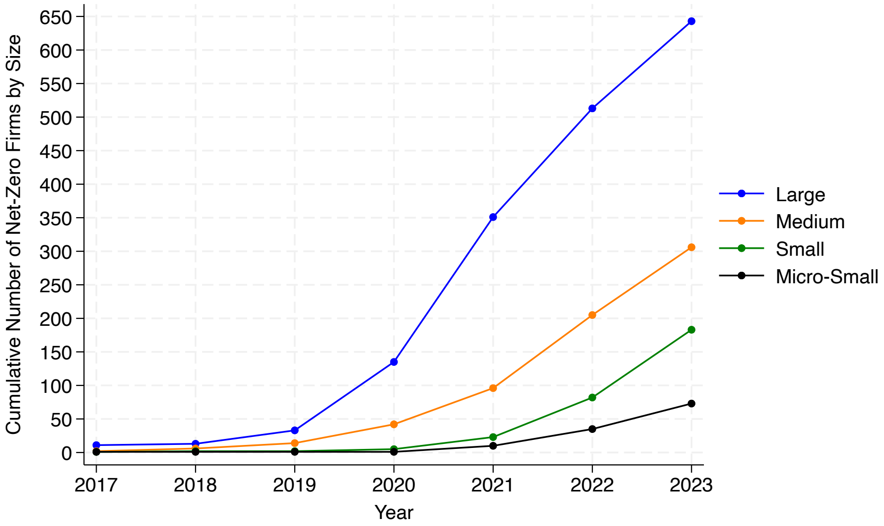

Figure 2: Cumulative number of firms that have made a Net Zero commitment by firm size (full SBTi sample). Firm size is measured by assets: "Large" ($10 billion or more), "Medium" ($2 billion to $10 billion), "Small" ($250 million to $2 billion), and "Micro-small" ($250 million or less).

2.1 Firm Size and Commitments to Decarbonize

Our first key finding is a strong positive relation between firm size and commitment to decarbonize, in the form of both Net Zero commitments and decarbonization investments.

Figure 2 illustrates that larger firms consistently led their smaller counterparts in making these commitments between 2016 and 2023. The lines representing the commitment trajectory of firms in each size group, measured as the number of firms that have already committed to Net Zero, exhibit steeper inclines for larger firms most of the time, underscoring their more pronounced dedication to Net Zero goals. This sequential pattern of commitments, with larger firms leading and smaller firms following, aligns with our model's key mechanism. In the model, large firms are better able to internalize the benefits of technological innovation and act as Stackelberg leaders, making early commitments that subsequently influence smaller firms through technological spillovers. The fact that commitment rates increase first for large firms, then medium firms, and finally smaller firms is consistent with this spillover channel rather than simply common shocks or industry trends, which would likely affect all size categories simultaneously. Figure 2 thus provides suggestive evidence for the coordination role of large firms in driving the Net Zero transition.

Table 1 confirms this relationship econometrically. The dependent variable "NZ" is a

Table 1: Effect of Firm Size on Decarbonization

	NZ			DI		
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Assets)	0.508***	0.572***		0.859***	1.009***	
	(0.055)	(0.044)		(0.104)	(0.060)	
Rank(Assets)			1.192***			2.193***
			(0.092)			(0.149)
Constant	0.074***	0.072***	-0.122***	0.163***	0.159***	-0.200***
	(0.018)	(0.001)	(0.016)	(0.039)	(0.002)	(0.027)
IndustryFE	No	Yes	Yes	No	Yes	Yes
Observations	3,560	3,560	3,560	3,560	3,560	3,560
Adj R^2	0.158	0.190	0.174	0.241	0.325	0.321

This table analyzes the relationship between firm size (log(assets) and rank(assets)) and decarbonization. Firm size is measured as of the end of 2017. The specification is: $Y_i = \beta \cdot \mathit{Firm\ Size}_i + \mathit{const} + \gamma_i + \epsilon_i$, where i refers to a firm, Y is either the Net Zero dummy "NZ" or the decarbonization investment dummy "DI", and γ_i refers to industry fixed effects. Standard errors, clustered at the industry level, are reported in parentheses below the coefficients. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

dummy equal to 1 if the firm makes a Net Zero commitment between 2016 and 2023 and 0 otherwise. The dependent variable "DI" is a dummy equal to 1 if the firm reports a decarbonization investment in the CDP survey between 2016 and 2023 and 0 otherwise. Whether measured by log assets or within-sample asset rank, firm size significantly predicts Net Zero commitment adoption and decarbonization investments, even after controlling for industry fixed effects. A one standard deviation increase in log assets (0.22) is associated with a 12.6 percentage point increase in the probability of making a Net Zero commitment, compared to a sample mean of 9%. The effect is even stronger for decarbonization investments: the same increase in firm size predicts a 22.2 percentage point higher probability of reporting such investments, relative to a sample mean of 19%.

2.2 Green Common Ownership and Commitments to Decarbonize

The second key pattern we document relates to "*green common ownership*". Unlike the broader common ownership literature which constructs detailed ownership networks based on portfolio holdings, we focus specifically on ownership by large institutional investors belonging to common major climate-focused coalitions. This narrower definition helps identify investors who are more likely to act as “common owners” around climate objectives.

Specifically, we define “NZ Investor Ownership” as the percentage of shares held by 13F institutional investors (i.e., institutional investment managers with over $100 million investment discretion) belonging to at least one of three major climate alliances: Net Zero Asset Managers, Climate Action 100+, and the UN-convened Net-Zero Asset Owner Alliance. Our theory is based on the notion that larger players, whether firms or investors, have stronger incentives and ability to make strategic commitments to decarbonize. Figure A.1 in the Appendix shows that these climate-focused alliances do tend to include larger institutional investors, with their holdings distribution shifted rightward compared to the full 13F universe. These alliances represent coordinated efforts by large institutional investors to influence portfolio companies’ climate strategies.

Appendix Table A.2 shows that firms with higher ownership by these climate-focused institutional investors are significantly more likely to make commitments to decarbonize. A one standard deviation increase in NZ Investor Ownership (0.11) is associated with a 17.5 percentage point higher probability of making a Net Zero commitment and an 11.5 percentage point higher probability of reporting decarbonization investments, controlling for industry fixed effects. These effects are economically significant compared to sample means of 9% for Net Zero commitments and 19% for decarbonization investments.

Our firm size and common ownership variables have a positive correlation of 0.32, as larger firms tend to have more institutional ownership due to, e.g., their inclusion in stock market indexes. However, Table 2 demonstrates that both channels independently predict commitments to decarbonize.[4] These results suggest the variables capture distinct channels: firm size allows individual firms to internalize spillovers within their industry, while common ownership facilitates coordination across firms.[5]

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[4] When included together with industry fixed effects, a one standard deviation increase in log assets predicts a 7.9 percentage point higher probability of Net Zero commitment and a 20.6 percentage point higher probability of decarbonization investment. Similarly, a one standard deviation increase in climate-focused institutional ownership is associated with a 15.1 percentage point increase in Net Zero commitment probability and a 5.3 percentage point increase in decarbonization investment probability.

[5] While an alternative interpretation is that climate-concerned institutional investors simply prefer to invest in firms more likely to make Net Zero commitments, our theory highlights that even purely profit-maximizing investors would have incentives to encourage such commitments due to technological spillovers. Distinguishing empirically between preference-based and profit-driven motivations is beyond the scope of this empirical analysis and is an important area for future research.

Table 2: Effect of Firm Size and Net Zero Investor Ownership on Decarbonization

	NZ			DI		
	(1)	(2)	(3)	(4)	(5)	(6)
NZ Investor Ownership	1.343***	1.374***	1.392***	0.486***	0.485***	0.483***
	(0.246)	(0.226)	(0.218)	(0.127)	(0.097)	(0.101)
Log(Assets)	0.303***	0.361***		0.784***	0.935***	
	(0.040)	(0.040)		(0.108)	(0.059)	
Rank(Assets)			0.719***			2.029***
			(0.065)			(0.157)
Constant	0.022*	0.019*	-0.099***	0.145***	0.140***	-0.192***
	(0.010)	(0.009)	(0.013)	(0.040)	(0.004)	(0.027)
Industry FE	No	Yes	Yes	No	Yes	Yes
Observations	3,560	3,560	3,560	3,560	3,560	3,560
Adj R^2	0.380	0.416	0.406	0.256	0.340	0.336

This table examines how firm ownership by Net Zero investors and firm size jointly affect decarbonization. NZ investors are defined as 13F investors belonging to one or more of the following climate alliances: Net Zero Asset Managers, Climate Action 100+, and the UN-convened Net Zero Asset Owner Alliance. 13F investor ownership data is from Backus et al. (2021), while total shares outstanding and price are from CRSP, measured as of the end of 2017. The specification is: $Y_i = \beta_1 \cdot \mathit{NZ\ Investor\ Ownership}_i + \beta_2 \cdot \mathit{Firm\ Size}_i + \mathit{const} + \gamma_i + \epsilon_i$, where i refers to a firm, Y is either the Net Zero dummy "NZ" or the decarbonization investment dummy "DI", firm size is proxied by log(assets) or rank(assets), and γ_i refers to industry fixed effects. Standard errors, clustered at the industry level, are reported in parentheses below the coefficients. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

2.3 Effects of Commitments on CO$_2$ Emission Intensity

Finally, Table 3 provides evidence that these commitments are not just all "cheap talk" or "greenwashing", but are indeed associated with meaningful changes in firm behavior. Firms that made Net Zero commitments or reported decarbonization investments show significantly larger reductions in their emission intensity (Scope 1 and 2 emissions scaled by assets) after 2017 compared to firms that did not make such commitments.

While these empirical patterns are consistent with our theoretical predictions, we acknowledge that larger firms and firms with greater institutional ownership may differ systematically in ways that affect their propensity to make Net Zero commitments. First, firms may strategically choose to make Net Zero commitments precisely when they anticipate be-

Table 3: Effect of NZ and DI on Emission Intensity Reduction

	Emissions Intensity Reduction		
	(1)	(2)	(3)
NZ (1/0)	0.035***		0.030**
	(0.010)		(0.011)
DI (1/0)		0.079**	0.073**
		(0.027)	(0.028)
Constant	0.887***	0.828***	0.822***
	(0.003)	(0.025)	(0.025)
Industry FE	Yes	Yes	Yes
Observations	1,595	1,595	1,595
R^2	0.07	0.07	0.07

This table examines the relationship between decarbonization indicators (Net Zero dummy and decarbonization investment dummy) and emission intensity reduction before and after 2017. Emission intensity is defined as the sum of Scope 1 and Scope 2 emissions scaled by assets. The emission intensity reduction dummy equals 1 if the average emissions-to-assets ratio decreased after 2017 compared to before. The specification is: $Emission\ Intensity\ Reduction_i = \beta \cdot Y_i + const + \gamma_i + \epsilon_i$, where i refers to a firm, Y is either the Net Zero dummy "NZ" or the decarbonization investment dummy "DI", and γ_i refers to industry fixed effects. Standard errors, clustered at the industry level, are reported in parentheses below the coefficients. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

ing able to reduce their emissions. In other words, the commitment may be signaling firms' private information about their future emission trajectory rather than causing the reduction (Bolton and Kacperczyk, 2021). Second, both the decision to commit and the ability to reduce emissions may be driven by common unobserved factors such as management quality, access to green technologies, or exposure to environmental regulations.

Therefore, the empirical patterns documented in this section—the relationship between firm size, common ownership, and commitment to decarbonize as well as the correlation between commitments and emission reductions— should be interpreted as providing motivating evidence for our theoretical framework rather than definitive causal estimates.

3 Model: Decarbonization and Technological Transition

Motivated by the evidence presented, we seek to build a model of strategic commitments to decarbonize, where by "strategic" we mean public commitments that are intended to influence the behavior of other firms.

We start with the simple building block model of decarbonization and green innovation that we will then use to study government policies such as carbon taxes and green innovation subsidies, and private sector policies such as Net Zero commitments.

3.1 Setup

Our economy features firms making two key decisions: production scale and green technology investment. Each firm i can transform k_i units of input into y_i units according to $y_i = f(k_i)$, where f is increasing, concave, and differentiable. Production generates emissions $e_i = \theta_i k_i$, where θ_i represents emission intensity.

Starting from an initial emission intensity θ_0, firms can invest in cleaner technology. A firm choosing a level of innovation or clean technology adoption Δ_i achieves emission intensity

$$\theta_i = \theta_0 - \Delta_i - \chi\bar{\Delta}, \tag{1}$$

where $\bar{\Delta} = \int_i \Delta_i di$ is the economy-wide average innovation, and $\chi \geq 0$ captures technological spillovers. The cost of innovation $C(\Delta)$ is increasing and convex in $\Delta \geq 0$.[6]

Social welfare is defined as

$$W = \int_i [f(k_i) - k_i - C(\Delta_i)]\, di - \mathcal{L}\left(\int_i (\theta_{i0} - \Delta_i - \chi\bar{\Delta})k_i di\right). \tag{2}$$

The first term in (2) captures production net of costs and investments in green technology, while the second term captures environmental damages. Aggregate emissions $E = \int_i e_i di$ hurt social welfare through an increasing and weakly convex damage function $\mathcal{L}(E)$. The marginal externality $\gamma = \mathcal{L}'(E)$ represents the social cost of carbon (SCC).

Environmental and technological externalities. We emphasize the presence of two interacting externalities, as in Acemoglu et al. (2012) and Aghion et al. (2016). In addition

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[6] This formulation is equivalent to letting firms choose their new emission intensity θ at a cost $C(\theta_0 - \theta - \chi\bar{\Delta})$, as in that case the technological externality acts as a reduction in the cost required to reach emission intensity θ, instead of a higher return to green innovation.

to the environmental externality, there is a technological externality, or "spillover", in the adoption of green technology. The spillover term $\chi\bar{\Delta}$ in (1) captures how one firm's green innovation reduces costs for others through knowledge diffusion, learning-by-doing, and supply chain improvements.

In the context of general innovation (and not just green technology), Bloom, Schankerman and Van Reenen (2013) estimate that social returns to innovation are twice as high as private returns, which would correspond to $\chi \approx 1$. Solar photovoltaic (PV) technology provides a clear example of innovation spillovers in clean technology. Between 2009 and 2019, solar PV module prices declined by 90% (IRENA, 2020) and Nemet (2019) finds strong knowledge spillovers through patent citations, inventor mobility, and public-private collaborations. Rapid improvements in wind turbine technology, with average turbine capacity increasing from 0.75 megawatts in 2000 to 5 megawatts by 2022 (IEA Wind TCP, 2023), have also been attributed to spillover effects in both scale and efficiency improvements (Grafström and Lindman, 2017).

Remark 1. Our model of green innovation can be interpreted in terms of technology choice. In Appendix C we show how our model can be mapped to a setting in which firms produce using two substitutable intermediate inputs, brown (b) and green (g), such that the brown intermediate input can be produced more easily but is more polluting. Δ can then be viewed as the share of production using green technology, and $C(\Delta)$ reflects the cost of using green technology instead of the more productive brown technology. In this formulation, the technological externality corresponds to a positive effect of adoption Δ on the productivity of the green technology.

3.2 Functional forms

To obtain transparent analytical results, we adopt the following functional forms. Firms have a quadratic production technology: $f(k) = (1 + a)k - \frac{k^2}{2}, \quad k \in [0, 1 + a]$, with $a > 0$. The innovation cost is also quadratic: $C(\Delta) = c\frac{\Delta^2}{2}$. We assume linear damages $\mathcal{L}(E) = \gamma E$, making the social cost of carbon γ independent of the level of emissions.[7]

To ensure interior solutions with positive but finite production and innovation, we require:

Assumption 1. *The cost of green innovation is sufficiently high:* $c > \gamma(1 + \chi)^2(2a/\theta_0 - \gamma)$, *and the initial emission intensity is sufficiently low:* $a > \gamma\theta_0$.

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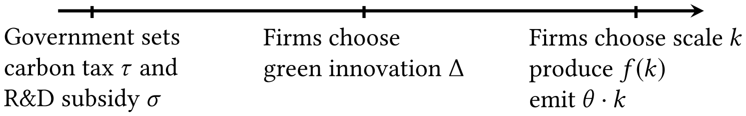
[7] We discuss extensions to convex damages in Section 6.

Figure 3: Baseline timing.



These conditions ensure two properties: (i) innovation remains finite under the first best ($\Delta < \infty$) and first-best output decreases with the social cost of carbon γ, and (ii) emission intensity θ and production k remain positive—hence complete shutdown of production is never optimal.

4 First-Best Allocation and Pigouvian Implementation

The first-best allocation maximizes social welfare (2), internalizing both the environmental externality and technological spillovers. This yields:

$$k^{FB} = \frac{a - \gamma\theta_0}{1 - \gamma^2(1+\chi)^2/c}, \quad \Delta^{FB} = \frac{\gamma(1+\chi)(a - \gamma\theta_0)}{c - \gamma^2(1+\chi)^2}.$$

These expressions reveal how optimal policy balances direct emission reduction through lower output and induced innovation. The numerator $(a - \gamma\theta_0)$ in k^{FB} corresponds to the optimal production without green innovation ($c = \infty$), where restricting output is the only way to limit emissions. With green innovation ($c < \infty$), a higher social cost of carbon γ has two effects: it still reduces the numerator in k^{FB}, but also leads to more innovation Δ^{FB}, thereby alleviating the output cost of emission reduction.

4.1 Implementation: Carbon Taxes and Green Innovation Subsidies

The first-best allocation can be implemented in a decentralized equilibrium using two Pigouvian instruments addressing the two externalities. The baseline timing is described in Figure 3; later on we augment this timeline with potential firm and government commitments.

The first instrument is a carbon tax τ per unit of emissions. A firm with emission intensity θ and production scale k pays a total carbon tax bill $\tau\theta k$. Since we abstract from uncertainty, this policy can be implemented either through explicit carbon pricing or a cap-and-trade system as in the European Emissions Trading System (Weitzman, 1974). We frame this policy in terms of a tax on emissions, but equivalently firms could receive a subsidy that scales with their emission *reduction*, as in Section 45Q of the U.S. Inflation Reduction Act which offers \$60-180 per ton of carbon captured and stored. The key point is that the reward or penalty is entirely based on the amount of emission reduction, and does not distinguish whether it is achieved through lower emission intensity or lower production.

The second instrument is a green innovation subsidy that rewards emission intensity reduction. A firm reducing its emission intensity by Δ receives $\sigma\Delta$. This captures various policies like green investment tax credits and technology-specific subsidies. A particularly relevant example is the U.S. Inflation Reduction Act (IRA) of 2022 introducing intensity-based subsidies for clean technology deployment. Section 45V establishes a production tax credit for clean hydrogen offering up to \$3 per kilogram when lifecycle greenhouse gas emissions are below 0.45 kg CO2e per kg of hydrogen. Unlike a carbon price that penalizes each unit of emissions equally regardless of output, this intensity-based approach rewards firms for cleaner production methods *per unit of output*, meaning firms can increase total emissions while still receiving maximum subsidies if they maintain low emission intensity. Similarly, Section 45X provides production credits per unit output for clean technology components like battery materials and solar panels, while Section 48C offers investment credits for manufacturing facilities that reduce emission intensity.

A firm facing carbon tax τ and innovation subsidy σ chooses (k, Δ) to maximize profits

$$f(k) - k - \tau(\theta_0 - \Delta - \chi\bar{\Delta})k - C(\Delta) + \sigma\Delta,$$

taking the average innovation $\bar{\Delta}$ as given. The firm's first-order conditions imply that setting

$$\tau^{FB} = \gamma, \quad \sigma^{FB} = \chi\gamma k^{FB}$$

implements the first-best allocation. The optimal carbon tax equals the social cost of carbon, while the optimal subsidy reflects both the strength of spillovers χ and the social value of emission reduction γk^{FB}. The point of the subsidy is to make firms internalize the effect of their individual innovation on the average innovation $\bar{\Delta}$, which helps towards reducing emissions without sacrificing production; this is why σ^{FB} increases with the optimal production scale k^{FB}, which reflects the opportunity cost of taxing carbon.

Interpretation of τ. While we refer to τ as a carbon tax or price for clarity, it should be interpreted more broadly as the *expected cost differential between high- and low-emission technologies*. This differential can arise through various channels: direct carbon pricing or cap-and-trade regime as in the EU's Emissions Trading System, regulatory compliance costs, or anticipated changes in relative input costs.

In the United States, where explicit carbon pricing has faced political resistance, firms may still expect implicit emission costs through environmental regulations, state-level clean energy requirements, and evolving market conditions that favor clean technologies.[8]

The cost differential also depends on expected energy price dynamics, as in Hicks' induced innovation hypothesis (Popp, 2002). As the energy transition progresses, reduced investment in fossil fuel infrastructure could lead to supply constraints and price volatility, while clean technology costs continue to decline (Engle 2024, Acharya et al. 2024). Thus, even without explicit carbon pricing, firms may face an effective tax on emissions through higher expected fossil fuel prices relative to clean alternatives.[9]

4.2 Time-Consistency of the Optimal Policy

A key aspect of decarbonization we want to study is how expectations about future policies affect current technological choices, and how governments may thus face a time-inconsistency problem.

In our model, the production stage happens after firms have chosen their innovation, thus firms choose k taking their emission intensity as given. At the earlier innovation stage, firms' decisions are affected both by the innovation subsidy σ at the time of innovation, and the carbon tax τ they expect in the future at the time of production. At the production stage, however, emission intensities are fixed hence the only policy tool left to curb emissions is the carbon tax τ. The crucial concern is whether governments are willing to maintain their announced policies after firms have made irreversible investments in green technology.

Definition 1. *A policy (τ, σ) requires commitment if at the ex-post stage, once emission intensities are fixed, the government can improve welfare by setting a different carbon tax $\tau' \neq \tau$.*

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[8] For example, the EPA's proposed power plant regulations (as of 2023) would require coal and gas plants to reduce emissions through carbon capture technology or face operational restrictions starting in 2030-2032. Similarly, California's Advanced Clean Cars II regulation mandates 100% zero-emission vehicle sales by 2035.

[9] Interestingly, aggregate clean innovation has two offsetting effects: the adoption of clean technology lowers the demand for fossil fuels, which mitigates the cost differential (which resembles our discussion of convex damages in Section 6); however, technological spillovers may further reduce the cost of clean energy, which raises the cost differential.

*A policy is **time-consistent** if it does not require commitment.*

The first-best policy (τ^{FB}, σ^{FB}) is time-consistent.[10] Intuitively, there is no point in using the future expected carbon tax to affect ex-ante innovation decisions, when green innovation can already be steered optimally through subsidies σ. This echoes results in the macro-finance literature on prudential regulation and bailouts: unconstrained ex-ante regulation can undo any excessive risk-taking induced by bailout expectations (e.g., Jeanne and Korinek, 2020). In particular, if there are no technological externalities, $\chi = 0$, then $\sigma^{FB} = 0$ which means that the first-best allocation can be achieved with a single instrument, a carbon tax set without commitment.

5 Constrained Policies and Second-Best Analysis

As shown in Section 4, achieving the first-best allocation requires two unconstrained Pigouvian instruments to address the two externalities. In the rest of the paper, we will consider constraints on these two instruments of the form

$$\tau \leq \bar{\tau}, \quad \sigma \leq \bar{\sigma},$$

where $\bar{\tau}$ and $\bar{\sigma}$ represent upper bounds on the feasible levels of carbon taxes and innovation subsidies, respectively, that capture political, institutional, or implementation challenges. When binding, these constraints make the first best unattainable. In this section, we study the second-best policy, i.e., the optimal policy subject to these constraints.

Different countries face different constraints in their ability to impose emission costs and support green innovation. Some contexts allow for more direct and measurable emission costs—whether through explicit carbon pricing, clear regulatory frameworks, or well-defined compliance costs—but face fiscal constraints on innovation support. In other contexts, directly imposing emission costs may be more challenging politically, but there is greater flexibility to support green innovation through subsidies and incentives, as exemplified by the U.S. Inflation Reduction Act of 2022. These are two extreme cases, and in practice every jurisdiction faces some positive, but asymmetric, constraint on each instrument. Understanding these polar cases helps illuminate the tradeoffs faced by policymakers working with different combinations of constraints.

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[10] For any given emission intensity, the ex-post optimal carbon tax is equal to the social cost of carbon γ. Since the first-best carbon tax is also equal to γ, the government has no incentive to deviate ex-post to a different carbon tax.

In addition to the potential upper bounds on fiscal instruments $\bar{\tau}$ and $\bar{\sigma}$, later we consider various assumptions on the commitment abilities of firms and governments. We start by analyzing optimal policies absent any firm and government commitments.

5.1 Constrained Innovation Subsidies

Suppose firms choose green innovation Δ anticipating a tax τ^{nc}, and τ^{nc} is then set ex post without commitment to maximize welfare once innovation Δ is already sunk. Moreover, suppose that the government does not have access to an innovation subsidy, that is, $\bar{\sigma} = 0$. Thus the government sets its only tool τ to solve

$$\begin{aligned} &\max_{k,\tau} f(k) - k - \mathcal{L}\left(\left(\theta_0 - \Delta(1+\chi)\right)k\right) \\ &\text{s.t. } f'(k) = 1 + \tau(\theta_0 - \Delta(1+\chi)) \end{aligned}$$

which leads to the standard result

$$\tau^{nc} = \gamma.$$

The ex-post optimal tax is the same as the first-best tax, equal to the social cost of carbon. We refer to $\tau = \gamma$ as the “Pigouvian tax”. Even without innovation subsidies, the ex-post optimal tax still equals the social cost of carbon, because it optimally trades off production and emissions given fixed technology choices.

However, the equilibrium without innovation subsidies departs substantially from the first-best allocation in the presence of technological externalities. Ex ante, firms invest in green technology Δ given an expected carbon tax τ^{nc} at the production stage, thus they solve:

$$\max_{\Delta,k} f(k) - k(1 + \tau^{nc}(\theta_0 - \Delta - \chi\bar{\Delta})) - C(\Delta)$$

taking the average innovation $\bar{\Delta}$ as given. Equating $\bar{\Delta} = \Delta$ in equilibrium, firms’ optimality conditions can be rewritten as

$$\begin{aligned} f'(k) &= 1 + \tau^{nc}(\theta_0 - \Delta(1+\chi)) \\ C'(\Delta) &= k\tau^{nc} \end{aligned}$$

Therefore we can characterize the no-commitment equilibrium as follows:

Proposition 1. *The no-commitment equilibrium without subsidies is*

$$k^{nc} = \frac{a - \gamma\theta_0}{1 - \gamma^2(1+\chi)/c}, \quad \Delta^{nc} = \frac{\gamma k^{nc}}{c}.$$

If $\chi > 0$ then the no-commitment equilibrium features suboptimal innovation and production

$$\Delta^{nc} < \Delta^{FB}, \quad k^{nc} < k^{FB}.$$

The lack of innovation subsidy leads to under-investment in green innovation relative to the first best. Each firm fails to internalize that increasing its own innovation would lead to a larger decrease in emission intensity for all firms, which would in turn lower their carbon tax bill for a given production scale k, and therefore allow them to increase their scale. As a result, firms end up under-producing as well.

In the next sections, we show that the technological externality creates a motive for firms to coordinate and increase innovation through firm commitments, and for governments to commit to a carbon tax τ^c exceeding the first-best tax, $\tau^c > \gamma$, in order to partially substitute for the lack of innovation subsidy.

5.2 Constrained Carbon Taxes

Having examined how firms respond to carbon taxes when innovation subsidies are constrained, we now analyze the opposite case to understand how innovation subsidies can partially substitute for missing carbon pricing. We assume that there are unconstrained subsidies σ, but the carbon tax is set at an exogenous and inefficiently low level $\bar{\tau} \leq \gamma$. This configuration can be interpreted as the case of countries in which green innovation subsidies have received a much broader political support than carbon pricing.

Firms' first-order conditions given a carbon tax $\bar{\tau}$ and an innovation subsidy σ are

$$\begin{aligned} f'(k) &= 1 + (\theta_0 - \Delta(1+\chi))\bar{\tau} \\ C'(\Delta) &= \bar{\tau}k + \sigma, \end{aligned}$$

showing that any level of innovation Δ can be implemented by setting a sufficiently high subsidy σ. We can thus rewrite the problem of the government as choosing k and Δ subject to a constraint tying k and $\bar{\tau}$:

$$\begin{aligned}
&\max_{k,\Delta} f(k) - k - C(\Delta) - \mathcal{L}([\theta_0 - \Delta(1+\chi)]\, k) \\
&\text{s.t. } f'(k) = 1 + \bar{\tau}[\theta_0 - \Delta(1+\chi)]
\end{aligned}$$

This leads to the following alternative second-best policy:

Proposition 2. *Without carbon tax ($\bar{\tau} = 0$), the optimal innovation subsidy is*

$$\sigma^*(\bar{\tau} = 0) = \gamma(1+\chi)a > \sigma^{FB}.$$

More generally, given a constrained carbon tax $\bar{\tau} \leq \gamma$, the optimal innovation subsidy is

$$\sigma^*(\bar{\tau}) = \chi k(\bar{\tau})\gamma + (\gamma - \bar{\tau})\left\{k(\bar{\tau}) - (1+\chi)(1 - k(\bar{\tau})/a)\right\}$$

where $k(\bar{\tau}) = \frac{a - \bar{\tau}\theta_0 - (1+\chi)^2 \frac{\bar{\tau}}{c}(\gamma - \bar{\tau})}{1 - \gamma\frac{\bar{\tau}}{c}(1+\chi)^2 - (1+\chi)^2 \frac{\bar{\tau}(\gamma-\bar{\tau})}{ac}}$.

In the first best, the only reason to subsidize innovation is to take advantage of the technological externality. The optimal subsidy with constrained carbon taxes is higher than the first-best subsidy, reflecting its dual role: addressing both technological spillovers and substituting for missing carbon pricing. Relative to the first best, this is, a highly inefficient way to reduce emissions since it targets emission intensity while letting production relatively undistorted if $\bar{\tau}$ is low, whereas the first best would require both innovation and a reduction in k. As the carbon tax increases toward γ, the optimal subsidy converges to the first-best level that only needs to address spillovers.

The formula for $\sigma^*(\bar{\tau})$ shows how the subsidy optimally balances these two objectives: the first term $\chi k(\bar{\tau})\gamma$ represents the standard correction for technological spillovers, while the second term captures the additional subsidy needed to partially substitute for suboptimal carbon pricing. A particularly simple case is when there is no technological externality, $\chi = 0$. In that case there would be no innovation subsidy in the first best ($\sigma^{FB} = 0$) but the optimal subsidy absent a carbon tax ($\bar{\tau} = 0$) is $\sigma = \gamma a$.

Another benchmark is the case without feasible green innovation, i.e., the cost c goes to infinity. Then $\Delta \longrightarrow 0$ and emission intensity remains at its initial level θ_0 and innovation subsidies have no effect, leaving emissions without carbon taxes at $E = \theta_0 a$, whereas the optimal carbon tax would reduce emissions to $E^{FB} = \theta_0(a - \gamma\theta_0)$.

Figure 4: Timing with firm commitments.

6 Firm Commitments

We now study the recent rise of *corporate* commitments, as documented in, e.g., Bolton and Kacperczyk (2021). Can firms benefit from committing, even if they are purely profit-maximizing? Our main result is that the technological externality creates a motive for firms to coordinate and increase innovation by acting as "Stackelberg leaders": their commitments incentivize all other firms to innovate, which ultimately reduces the committing firms' own cost of decarbonization through lower carbon tax bills.

In our framework, firm commitments represent irreversible investments in green technology that reduce emission intensity above and beyond what non-strategic, atomistic firms would do. While firms can adjust their production scale k after making a commitment, their choice of green innovation Δ determines their future emission intensity. We show that firm commitments can effectively substitute for missing innovation subsidies, but cannot replace carbon taxes. Indeed, the very existence of carbon taxes is what creates the profit incentive for firms to make credible commitments.

We model this interaction as a game with the following timing:

1. The government acts first by announcing policies.
2. Within the private sector, coalition of size μ moves first, choosing its green innovation Δ^l.
3. Outside firms of mass $1-\mu$ observe this commitment, and choose their own innovation Δ^s.
4. Finally, firms choose their production scales (k^l, k^s) given their emission intensities.

The solution concept is subgame perfect equilibrium. Figure 4 shows the timeline with firm commitments, with the node in red highlighting the difference with Figure 3.

6.1 Stackelberg Equilibrium in Green Innovation

In this section we take the carbon tax τ as given; we will later let the government optimize τ taking into account the private sector's response, including through commitments.

Suppose that the economy is populated by one large firm of "size" $\mu \in [0,1]$ and a measure $1-\mu$ of small firms. "Large" means that individual actions by this single firm can affect the equilibrium, *and the firm internalizes this.* The limit $\mu \to 0$ corresponds to the previous model with only atomistic firms, in which no firm is willing to commit.

Depending on the sector, one can interpret the large firm as either an actual market leader with a sizeable market share, or as a *coalition* of a mass μ of small firms that can coordinate their actions, for instance because they are all owned by a large common institutional investor. Most of the literature on common ownership has emphasized anti-competitive effects in product markets, although recent work has highlighted that in the presence of innovation spillovers, common ownership may have a bright side, e.g., López and Vives (2019) and Antón et al. (2021). Our model also emphasizes the potential benefits of common ownership for the green transition.

The coalition size μ can capture various forms of coordination beyond common ownership: industry consortia like the First Movers Coalition launched at the COP26 (where major companies commit to purchase emerging clean technologies to help create early markets, similar to how advance market commitments for vaccines guarantee demand to accelerate their development), supply chain partnerships where large firms influence their suppliers' technology choices, or sectoral initiatives where firms share decarbonization knowledge and best practices. It could also reflect a coalition of cities and states, such as the "United States Climate Alliance" and "America's Pledge", both founded in 2017 in response to the U.S. withdrawal from the Paris Agreement.

Non-Committers. Given the innovation Δ^l by the large firm, and the conjectured innovation Δ^s by other small firms, each individual small firm with initial emission intensity θ_0 solves the following problem:

$$\max_{\Delta,k} \quad f(k) - C(\Delta) - k - \tau(\theta_0 - \Delta - \chi\left[\mu\Delta^l + (1-\mu)\Delta^s\right])k + \sigma\Delta.$$

Hence firms only care about their carbon bill, not directly about reducing damages. As a result the only large firm commitment that matters for small firms (conditional on τ) is Δ^l. The fixed point to this problem yields reaction functions for small firms as a function of the large firm's commitments $\left\{k(\Delta^l,\tau,\sigma),\Delta^s(\Delta^l,\tau,\sigma)\right\}$, solving the following system:

$$\begin{aligned} f'(k^s) &= 1+\tau(\theta_0-\Delta^s-\chi\left[\mu\Delta^l+(1-\mu)\Delta^s\right]), \\ c\Delta^s &= \tau k+\sigma. \end{aligned}$$

Our functional forms imply the following closed-form solutions for the small firms' policy functions for investment

$$k^s(\tau,\sigma,\Delta^l) = a-\tau(\theta_0-\Delta^s-\chi\left[\mu\Delta^l+(1-\mu)\Delta^s\right]$$

and innovation

$$\Delta^s(\tau,\sigma,\Delta^l) = \frac{\tau\left(a-\tau\theta_0\right)+\sigma}{c-\tau^2(1+\chi(1-\mu))}+\frac{\chi\tau^2\mu}{c-\tau^2(1+\chi(1-\mu))}\Delta^l, \tag{3}$$

where we assume that the technological externality is not too strong ($c>\tau^2\left[1+\chi(1-\mu)\right]$) to get a finite solution. Equation (3) captures small firms' best-response innovation Δ^s given firm commitments Δ^l by firms in the coalition and government policies τ and σ.

Committers. In our setting, the only way some firms can make a commitment that affects the equilibrium is through their ex-ante choice of green innovation Δ. The large firm or coalition of firms making a commitment acts as Stackelberg leader, and solves

$$\max_{\Delta,k} f(k)-C(\Delta)-k-\tau(\theta_0-\Delta(1+\chi\mu)-(1-\mu)\chi\Delta^s(\Delta))k+\sigma\Delta$$

taking as given government policies and the reaction function of outside firms. The large firm must take into account how small firms' innovation will respond to its own innovation or decarbonization investment: $\frac{\partial\Delta^s}{\partial\Delta^l}=\frac{\tau^2\chi\mu}{c-\tau^2(1+\chi(1-\mu))}>0$. Naturally, the larger μ, the stronger the innovation externalities $\chi\bar{\Delta}$ and in turn the more each individual small firm outside the coalition responds. When firm commitments are stronger (larger Δ^l), small firms outside the coalition are able to increase production k^s, and given this higher scale the returns to their own green innovation are also higher. For this reason the effect of firm commitments on green innovation by outside firms is also increasing in τ: a higher tax makes outside firms more responsive to firm commitments, because the innovation externality has a stronger impact on scale k^s when carbon taxes are higher. Conversely, in a country with low carbon taxes, production scale becomes decoupled from green innovation and thus there are no spillovers from large firms' commitments to outside small firms.

We can describe the full Stackelberg equilibrium in closed form as follows:

Proposition 3 (Equilibrium with Firm Commitments)**.** *Given government policies* (τ, σ)*, equilibrium firm policies are given by:*

$$\Delta^l(\tau,\sigma) = \frac{c(\tau(\mu\chi+1)(a-\theta_0\tau)+\sigma)+\tau^2(\tau(\chi+1)(\theta_0\tau-a)+\sigma(-((\mu-1)\chi(\mu\chi-1))-1))}{c^2-c\tau^2\left(\chi\left(\mu^2\chi+2\right)+2\right)+\tau^4(\chi+1)^2}$$

and

$$\begin{aligned}
k^l(\tau,\sigma) &= \frac{c}{\tau\left[1+\chi\left(\mu+(1-\mu)\frac{\tau^2\chi\mu}{c-\tau^2(1+\chi(1-\mu))}\right)\right]}\Delta^l(\tau,\sigma)\\
\Delta^s(\tau,\sigma) &= \frac{\tau\left(a-\tau\theta_0\right)+\sigma}{c-\tau^2(1+\chi(1-\mu))}+\frac{\tau^2\chi\mu}{c-\tau^2(1+\chi(1-\mu))}\Delta^l(\tau,\sigma)\\
k^s(\tau,\sigma) &= \frac{c\left(a-\tau\theta_0\right)+\tau\sigma(1+\chi(1-\mu))}{c-\tau^2(1+\chi(1-\mu))}+\frac{c\tau\chi\mu}{c-\tau^2(1+\chi(1-\mu))}\Delta^l(\tau,\sigma)
\end{aligned}$$

With a Pigouvian carbon tax $\tau = \gamma$ and no innovation subsidy $\sigma = 0$, we observe that when $\mu \to 1$, the economy is dominated by the large firm, and its commitment leads to the first-best allocation: $\lim_{\mu\to 1}\Delta^l = \Delta^{FB} = \gamma(1+\chi)\frac{a-\gamma\theta_0}{c-\gamma^2(1+\chi)^2}$. This occurs because the large firm internalizes both the environmental externality thanks to the tax $\tau = \gamma$, and the innovation spillover effects. When $\mu \to 0$ instead, the large firm becomes negligible, and we recover the no-commitment equilibrium: $\lim_{\mu\to 0}\Delta^l = \Delta^{nc} = \gamma\cdot\frac{(a-\gamma\theta_0)}{c-\gamma^2(1+\chi)}$. The absence of significant firm commitments leads to underinvestment in innovation.

Proposition 3 also reveals how committing firms take into account two sources of spillovers: direct externalities *within* the coalition μ of committers, and spillovers on the mass $1-\mu$ of small firms outside the coalition characterized by (3). When μ is small, firm commitments only have a small effect on outsiders, hence it is not optimal for committers to act strongly. As the large firm only represents a tiny fraction of the market, its ability to influence other firms is limited. Realizing that the impact of green investments on non-committers is minimal, the large firm has little incentive to increase its innovation efforts significantly. Conversely, when μ is large, firm commitments have a large effect on outsiders but there are not many outsiders to influence anyway, and most of the adjustment comes directly from committers.

Therefore, it is at intermediate levels of μ that the large firm's commitment has the most substantial impact on small firms. The innovation spillovers are maximized in that case because commiters are sufficiently large to exert a significant influence, and there is still a sizeable population of small firms to be influenced.

6.2 Welfare Implications of Firm Commitments

We now study how firm commitments impact welfare and how this depends on government policies. We proceed in three steps. First, we show that firm commitments cannot improve welfare when innovation subsidies are unconstrained—an irrelevance result that highlights why commitments matter only in second-best settings. Second, we establish a clear welfare ranking showing that carbon taxes remain essential even with firm commitments. Finally, we demonstrate that profit-maximizing firms have incentives to make commitments even without any altruistic motives.

Denote $W(\tau, \sigma, \mu)$ the welfare, defined as net output minus environmental damages as in (2), under a carbon tax τ, an innovation subsidy σ, and optimal firm commitments by a coalition of size μ as described in Proposition 3.

Irrelevance of Firm Commitments with Optimal Innovation Subsidies. We first show a simple irrelevance result: in the presence of unconstrained green innovation subsidies, firm commitments (that is, $\mu > 0$) cannot increase welfare relative to an equilibrium without commitments ($\mu = 0$).[11]

Proposition 4. *Firm commitments cannot improve welfare if the government can set an optimal innovation subsidy:*

$$\max_{\sigma} W(\bar{\tau}, \sigma, \mu) \leq \max_{\sigma} W(\bar{\tau}, \sigma, 0) \quad \forall \mu \in [0, 1].$$

In particular, firm commitments can never achieve the first-best welfare W^{FB} if the carbon tax is below the social cost of carbon, $\bar{\tau} < \gamma$, even as $\mu \to 1$.

This result embodies an important lesson: firm commitments cannot substitute for carbon taxes, even though they can effectively replace innovation subsidies. The intuition is that the profit motive for commitments (reducing future carbon tax bills) requires meaningful carbon pricing in the first place. More precisely, the lower curve $\max_{\sigma} W(\bar{\tau}, \sigma, \mu)$ is weakly below $\max_{\sigma} W(\bar{\tau}, \sigma, 0)$ and sometimes strictly below due to misallocation of green

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[11] For intermediate $\mu \in (0, 1)$, firm commitments can even decrease welfare relative to $\mu = 0$ by causing misallocation of green innovation, with too much green innovation by committing firms and too little by outside firms. In our numerical examples, we find that this effect is quantitatively small.

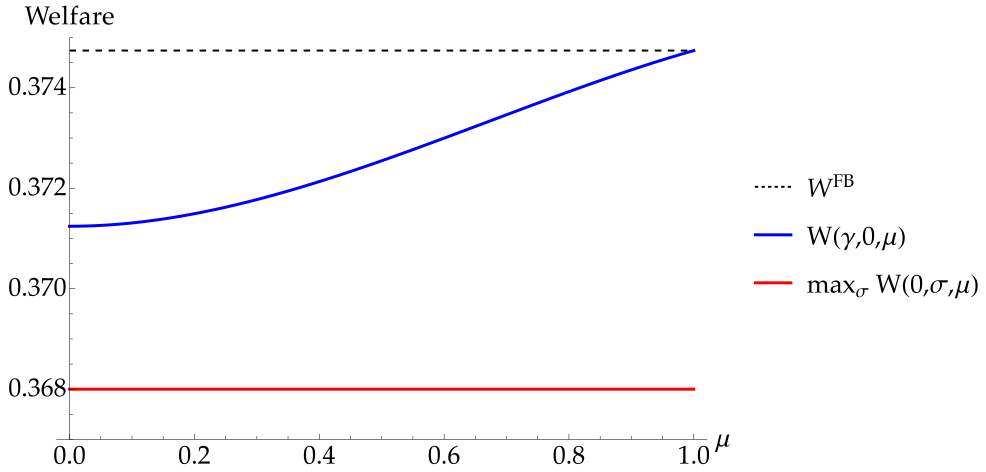

Figure 5: Welfare as a function of the size of the firm commitment coalition μ, compared to three benchmarks: first best ($\mu = 1$), Pigouvian carbon tax without innovation subsidies ($\tau = \gamma$, $\mu = 0$), and no carbon taxes but optimal subsidies ($\bar{\tau} = 0$).

innovation. Firm commitments are thus most useful when the carbon tax is relatively less constrained, as in the case of Europe; as we discuss below, they also make carbon taxation more credible by lowering the required tax towards the Pigouvian level.

Welfare Comparisons. Our main normative result compares welfare under different configurations of government policies and firm commitments:

Proposition 5 (Welfare ranking). *Suppose that technological externalities are not too large:*

$$\chi \leq \frac{1}{2\gamma^2}\left\{c + \sqrt{c\left(\sqrt{c}-\gamma\right)\left(3\gamma+\sqrt{c}-4\gamma^2\theta_0/a\right)} + \gamma\sqrt{c}\right\} - 1, \tag{4}$$

where the right-hand side is always positive under Assumption 1. Then for any $\mu \in [0,1]$ *we have the following welfare ranking:*

$$\max_\sigma W(0,\sigma,\mu) \leq W(\gamma,0,0) \leq W(\gamma,0,\mu) \leq W(\gamma,0,1) = W^{FB}.$$

Proposition 5 shows a simple ranking. First, carbon taxes are essential, in the sense that the welfare without tax ($\bar{\tau} = 0$) is lowest even when optimal subsidies and firm commitments are available. Subsidies and firm commitments are mostly targeting green innovation, but this is never sufficient and scaling down production remains necessary. Without carbon tax the private sector always overproduces ($k = a$), which ends up generating too many emissions in spite of the lower emission intensity achieved thanks to green innovation.

Figure 5 illustrates the result by showing the different values of welfare, as a function of the strength of firm commitments measured by μ. In the case of a Pigouvian carbon tax $\tau = \gamma$, as μ increases towards 1, $W(\gamma, 0, \mu)$ converges to the first-best welfare. With optimal innovation subsidies but no carbon tax ($\bar{\tau} = 0$), welfare $\max_\sigma W(0, \sigma, \mu)$ is almost unaffected by the strength of firm commitments μ, consistent with Proposition 4.

A central point is that firm commitments improve upon welfare and are optimal from the perspective of firms in the coalition even though we make the conservative assumption that *all firms are purely profit-maximizing* and do not take into account damages in their objective function. We thus abstract from any ESG-motives that may lead firms to invest in green technology and reduce emissions above and beyond the simple pecuniary benefits of reducing their expected carbon tax bill. These extrinsic preferences for emission reduction could be expressed, for instance, through ESG-investing making firms' cost of capital contingent on their emissions (Pastor et al., 2021; Pedersen, 2023). One of our main points is that even without such preferences there may be an economic rationale to "over-invest" in green technology from the perspective of large firms or institutional investors in the presence of technological externalities.

Our model provides a new perspective on the effect of common ownership on firm decisions. While the literature has focused on negative effects working through diminished competition between firms owned by the same institutional investors, we highlight a potential brightside of common ownership.[12] The mechanism is closely related since in both the cases of market power and our case with technological externalities, common ownership leads firms to internalize externalities on other firms. In the case studied by the literature they internalize the effect of their pricing and production decisions on other firms' profits and respond by increasing prices and weakening competition. In our case firms internalize the effect of their green technology adoption on other firms' ultimate emission intensity. In the next section we introduce an additional consideration which is the endogenous response of government policies (i.e., carbon taxes) to firms' commitments.

Remark 2 (Convex damages.). For simplicity, in the baseline model we assume that damages are linear and therefore the social cost of carbon γ is a constant parameter, independent of

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[12] López and Vives (2019) and Antón et al. (2021) are two exceptions that also highlight the potential benefits of common ownership on general innovation that affects productivity. We focus on *green* technology that affects emission intensity instead of productivity, in the context of other frictions and policies, i.e., environmental externalities and carbon taxes.

emissions and policies. When damages are convex (as in standard specifications such as Nordhaus 2017 and Golosov et al. 2014), the marginal externality γ increases with emissions. Most of our analysis goes through unchanged, once we interpret γ as the marginal externality, i.e., $\gamma = \mathcal{L}'(E)$, and keeping in mind that γ is now an endogenous variable. The only noteworthy implication of this extension is that as firm commitments strengthen (μ increases), even the ex-post Pigouvian tax $\tau = \gamma$ falls. The green innovation induced by firm commitments reduces the marginal social cost of carbon γ and thus the ex-post optimal carbon tax. In turn, the endogenous response of the carbon tax amplifies the profits that firms can gain by committing, i.e., by going from $\mu = 0$ to $\mu > 0$, very much like in the case with government commitments analyzed in Section 7.[13]

6.3 Incentives to Commit

Profits in the equilibrium with firm commitments are higher than in the equilibrium without firm commitments, for both the firms that commit ("committers") and the firms that do not ("non-committers"). For both types of firms we can compute the increase in profits Π_i where

$$\Pi_i = f(k_i) - k_i - C(\Delta_i) - \bar{\tau} \left[\theta_0 - \Delta_i - \chi \bar{\Delta}\right] k_i + \sigma \Delta_i$$

resulting from a shift in the equilibrium from no firm commitments to commitments by a coalition of size μ. For now we hold policies fixed; in the next section we also allow policies to vary in response to firm commitments.

Figure A.2 shows the profits for firms making commitments ("committers") and firms outside the coalition ("non-committers"). Profits are higher relative to the case $\mu = 0$ which corresponds to no firm commitments. The increase in profits for the committers shows the strength of their incentives to commit, that is, how much they gain by shifting the equilibrium thanks to technological externalities, even without any extrinsic preferences for lower emissions.

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[13] Making damages convex in emissions does not lead to equilibrium multiplicity in spite of the limited government commitment, because firms' green technology investments and the government's future carbon tax policy become strategic *substitutes*. If firms expect a higher carbon tax in the future, they respond by investing more in green technology, which reduces emissions and thus the future optimal carbon tax, which is inconsistent with the initial expectation of a higher carbon tax. This prevents amplification effects or self-fulfilling equilibria in which carbon taxes end up low simply because firms expect them to be low. Concave damages, on the other hand, would lead to strong amplification, potentially even generating equilibrium multiplicity as in, e.g., Biais and Landier (2022), who argue that lack of government commitment to future emission caps and strategic complementarities between firms can lead to equilibrium multiplicity, as the government finds it optimal to cap emissions ex post only if firms have sufficiently invested in abatement technologies.

The non-committing firms (in mass $1-\mu$) obtain even higher profits than the committers, and the gap increases with μ. This implies that ex-post committers have an incentive to deviate and free-ride on the commitments of the coalition, as this would yield the positive externalities from the firm commitments without the cost of having to "over-invest" in the clean technology. In our interpretation, however, the firms in the coalition would not be able to deviate unilaterally, as they are owned by a large institutional investor acting as common owner.

7 Government Commitments

We have seen that government policy is time-consistent if two unconstrained Pigouvian instruments, carbon taxes and green innovation subsidies, are available. In a second-best environment, there is a role for government commitments to carbon taxes above the ex-post optimal level, in order to give the private sector stronger ex-ante incentives to reduce emission intensity.

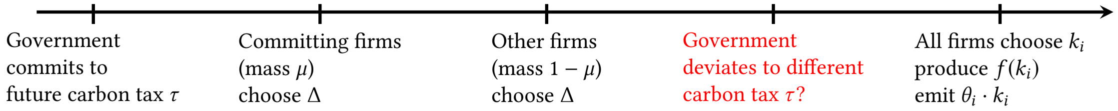
We now extend the model to allow for both firm and government commitments and study their interactions. We focus on the case of constrained innovation subsidies, since this is the case that makes government and firm commitments relevant. Hence to simplify we assume $\sigma = 0$ throughout this section.

We model government commitments as promises to increase carbon taxes in the future. We first study an important benchmark case where government has full commitment power, that is, any announced future carbon tax is automatically considered credible by the private sector. This helps isolate the government's preferred policy absent credibility constraints. We then turn to the more realistic case of limited commitment ability, where excessively high carbon taxes may not be credible due to ex-post political economy considerations. We explicitly model governments' commitment ability and then how firm commitments and government promises and their credibility interact.

The main results in this section are two-fold. First, the government has an incentive to commit to a future carbon tax that exceeds the social cost of carbon and therefore the ex-post optimal Pigouvian level $\tau = \gamma$. Promising a tax $\tau > \gamma$ is an indirect way to strengthen the private sector's incentives to invest in green innovation and reduce emission intensity. However, this government commitment policy is time-inconsistent and thus not always credible.

Our second main finding is that *firm commitments improve government credibility.* Stronger

Figure 6: Timing with firm and government commitments.



firm commitments (i.e., a larger μ) take away part of the burden from the government and reduce the need for an abnormally high carbon tax to stimulate innovation. Thanks to the green innovation induced by strong firm commitments, the temptation to lower the carbon tax ex post is weaker, which makes the initial commitment more credible.

Figure 6 shows the timeline with both firm and government commitments, with the node in red highlighting the difference with Figure 4.

7.1 Benchmark: Full Government Commitment

We have seen that with two unrestricted policy instruments, carbon taxes and innovation subsidies, the government can achieve the first best and does not face any time-inconsistency problem while doing so. Suppose now that the government can set a tax τ^c that differs from the ex post optimum level $\tau^{nc} = \gamma$. We start with a benchmark case, assuming the government has full commitment ability, in the sense that any promise τ^c is considered credible by the private sector.

No Firm Commitments. The government takes into account that firms' choice of Δ depends on the carbon tax they expect at the production stage. Given a carbon tax commitment τ^c and no firm commitments (i.e., $\mu = 0$), firms choose (k, Δ) to maximize profits $f(k) - k\left[1 + \tau^c(\theta_0 - \Delta)\right] - C(\Delta)$, with optimality conditions:

$$f'(k) = 1 + \tau^c(\theta_0 - \Delta), \tag{5}$$

$$C'(\Delta) = k\tau^c. \tag{6}$$

Conversely, the government can use τ^c to implement any pair (k, Δ) satisfying the following implementability condition combining (5)-(6):

$$f'(k) = 1 + \frac{C'(\Delta)}{k}(\theta_0 - \Delta). \tag{7}$$

The following result characterizes the optimal commitment, defined as maximizing social welfare subject to (7):

Proposition 6. *Suppose that $a > 2\gamma\theta_0$. Without innovation subsidies, the optimal carbon tax under full commitment $\kappa = \infty$ and no firm commitments is between γ and $\gamma(1+\chi)$.*

The first-best optimality conditions are $f'(k) = 1 + \gamma\theta$ for production, and $C'(\Delta) = \gamma(1+\chi)k$. It is impossible to satisfy both at the same time, but committing to a tax τ^c between γ and $\gamma(1+\chi)$ strikes a middle ground.

Figure A.3 illustrates the result by showing the optimal tax as a function of the technological externality parameter χ. In the absence of innovation subsidies, the government finds it optimal to commit to a carbon tax that is *above* the social cost of carbon, $\tau^c > \gamma$. By making carbon emissions privately more costly, the higher carbon tax stimulates innovation and thus allows to partly take advantage of technological externalities in emission reduction. The efficient way to stimulate innovation would be to use a "carrot" subsidy. Stimulating innovation through the carbon tax "stick" improves upon the no commitment outcome, but comes at the cost of lowering production much more than would be desirable in the first best. Proposition 6 shows again that without technological externalities ($\chi \to 0$) no commitment is needed and the Pigouvian carbon tax $\tau = \gamma$ is optimal both ex ante and ex post.

In the case of a constraint the carbon tax $\tau \leq \bar{\tau}$ but unconstrained innovation subsidies, the time-consistency constraint is only binding for carbon taxes and irrelevant for the choice of subsidies. This means that given a constrained carbon tax $\bar{\tau}$, the optimal innovation subsidy under commitment is the same as described in Section 5.2.

Firm Commitments. With firm commitments of size μ, the government solves a similar problem but now takes into account the private sector's response to the anticipated carbon tax τ by both committers and non-committers, captured by the reaction functions $\Delta^i(\tau, \mu), k^i(\tau, \mu)$. Figure A.4 shows the solution to this problem, i.e., the optimal government commitment τ^c as a function of μ. The optimal government commitment falls with the strength of firm commitments μ, and converges to the social cost of carbon γ when $\mu \to 1$ as firm commitments become sufficient to take full advantage of the technological externalities.

7.2 Limited Government Commitment

We now turn to the more realistic case of limited commitment ability. We acknowledge the fact that governments cannot commit to *any* level of carbon tax: in the future, they may find it too costly to impose an excessive carbon tax due to, e.g., political economy considerations. As a result government commitments have limited power in incentivizing the adoption of green technology.

Our main finding is that firm commitments improve government credibility. When more firms commit (higher μ), the government's optimal commitment is less harsh, getting closer to its ex-post optimal tax γ, which makes the commitment more credible since the government gains relatively less ex-post from deviating.

Modeling Government Credibility. We model government commitments as promises about future carbon taxes.[14] The objective of such promises is to provide stronger incentives for green innovation ex ante, but these promises may have limited credibility because they entail deviating from the ex-post optimum. We start with a simple model of governments' commitment ability, before solving from the government's optimal commitment and how it is affected by firm commitments.

The ex-post social welfare given a carbon tax τ, once innovation Δ^i has taken place for firms of type $i = l, s$, is

$$V(\Delta^l, \Delta^s, \tau, \mu) = \mu[f(k^l) - k^l] + (1-\mu)[f(k^s) - k^s] - \gamma\left\{\mu(\theta_0 - \Delta^l - \chi\bar{\Delta})k^l + (1-\mu)(\theta_0 - \Delta^s - \chi\bar{\Delta})k^s\right\}$$
$$\text{where} \quad f'(k^i) = 1 + \tau(\theta_0 - \Delta^i - \chi\bar{\Delta})k^i, \quad \text{for } i = l, s \tag{8}$$

Equation (8) captures the fact that firms adjust their production according to the tax τ, which is why changing the tax may improve welfare. For instance, if the government promised a high carbon tax to incentivize green innovation ex ante, sticking to the promised tax implies a lower production than deviating to a lower tax.

Given linear damages, the ex-post optimal tax is extremely simple, always equal to γ. Therefore deviating from a commitment τ^c, given that firms chose Δ believing the tax would

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[14] We study a "Ramsey planning problem" which restricts the government's policy set to linear carbon taxes. Philippon and Wang (2022) show that allowing for tournament mechanisms that reward the best-performing firms and punish the worst-performing ones can simultaneously provide correct ex-ante incentives and alleviate the government's time-inconsistency problem. The idea is to let firms compete ex-ante to obtain the rewards, and in the current context the mechanism would take the form of a sophisticated non-linear carbon tax (in spite of linear damages), that redistributes from the most polluting firms to the least polluting firms.

be τ^c, yields an ex-post welfare gain

$$\begin{aligned}\Delta V(\tau^c,\mu) &= \max_{\tau} V(\Delta^l(\tau^c,\mu),\Delta^s(\tau^c,\mu),\tau,\mu) - V(\Delta^l(\tau^c,\mu),\Delta^s(\tau^c,\mu),\tau^c,\mu)\\ &= V(\Delta^l(\tau^c,\mu),\Delta^s(\tau^c,\mu),\gamma,\mu) - V(\Delta^l(\tau^c,\mu),\Delta^s(\tau^c,\mu),\tau^c,\mu),\end{aligned}$$

where the firms' policy functions $\Delta^i(\tau^c,\mu)$ are given by Proposition 3 specialized to $\sigma = 0$.

We model limited commitment ability by assuming that the government must incur a cost $\kappa \geq 0$ if it deviates from its commitment:

Definition 2. *A carbon tax τ is credible if and only if the following incentive compatibility (IC) constraint holds:*

$$\Delta V(\tau,\mu) \leq \kappa \tag{9}$$

For a government commitment to be credible, the promised tax τ must not be too far away from the ex-post optimal tax γ, so that the ex-post welfare gain from deviating to $\tau = \gamma$ remains smaller than the parameter κ that captures, e.g., the loss in reputation. If $\kappa = 0$ then the government will always deviate to $\tau = \gamma$ so no commitment is possible. A higher κ means a stronger commitment ability. The limit $\kappa = \infty$ corresponds to a government with full commitment as in Section 7.1.

Optimal Government Commitment. The government should take its own capacity κ into account when setting an optimal commitment, and realize that it is allowed to depart somewhat from the ex-post optimum $\tau = \gamma$ if it can improve ex-ante incentives to innovate. Thus the optimal government commitment is the solution to a principal-agent problem of the ex-ante government with its future incarnation:

Definition 3. *Given firm commitments of strength μ, the optimal credible government commitment $\tau^c_{IC}(\mu,\kappa)$ is the carbon tax τ that maximizes social welfare*

$$\begin{aligned}&\mu\left\{f(k^l(\tau,\mu)) - k^l(\tau,\mu) - C(\Delta^l(\tau,\mu))\right\} + (1-\mu)\left\{f(k^s(\tau,\mu)) - k^s(\tau,\mu) - C(\Delta^s(\tau,\mu))\right\}\\ &\quad - \gamma\left\{\mu(\theta_0 - \Delta^l(\tau,\mu) - \chi\bar{\Delta}(\tau,\mu))k^l(\tau,\mu) + (1-\mu)(\theta_0 - \Delta^s(\tau,\mu) - \chi\bar{\Delta}(\tau,\mu))k^s(\tau,\mu)\right\}\end{aligned}$$

subject the government's incentive compatibility constraint (9).

By definition, we have $\tau^c(\mu) = \lim_{\kappa\to\infty}\tau^c_{IC}(\mu,\kappa)$: the optimal credible government commitment converges to the optimal commitment as credibility becomes infinite. While in

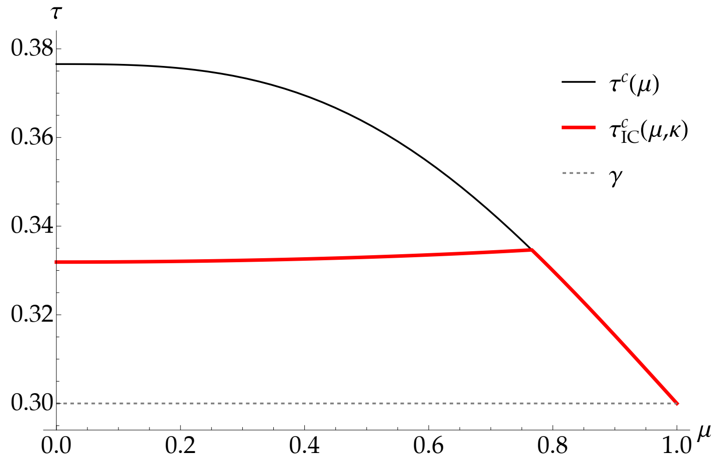

Figure 7: Optimal credible government commitment $\tau^c_{IC}(\mu, \kappa)$ as a function of μ. The vertical line denotes $\underline{\mu}$.

general $\tau^c_{IC}(\mu, \kappa)$ cannot be fully solved analytically, we characterize the solution before showing numerical results in Figures 7 and A.5.

The welfare wedge $\Delta V(\tau^c(\mu), \mu)$ decreases with μ and goes to zero as $\mu \to 1$, hence there exists a minimal firm coalition size $\underline{\mu}$ (decreasing in the government's commitment ability κ) such that the IC constraint (9) is slack for $\mu \geq \underline{\mu}$ but binding for $\mu < \underline{\mu}$. The carbon tax is thus determined by the government's *ability to tax carbon* in the region $\mu < \underline{\mu}$, and by the government's *willingness to tax carbon* in the region $\mu \geq \underline{\mu}$.

In the region $\mu < \underline{\mu}$, the government would like to commit to a higher carbon tax $\tau^c(\mu)$ but is unable to, as such a high tax would not be credible given its limited commitment capacity κ. The government then optimally commits to a lower, but credible, carbon tax $\tau^c_{IC}(\mu, \kappa) < \tau^c(\mu)$. In this region the tax $\tau^c_{IC}(\mu, \kappa)$ can be found by solving for the tax τ that makes the IC constraint (9) bind.

In the region $\mu \geq \underline{\mu}$, the optimal commitment $\tau^c(\mu)$ studied in Section 7.1 is sufficiently low and close to the Pigouvian tax $\tau = \gamma$ that the welfare gain from deviating ex post to $\tau = \gamma$ is smaller than κ. As a result the government can resist the temptation to lower the carbon tax ex post, and can credibly commit ex ante to $\tau^c(\mu)$.

7.3 How Firm Commitments Affect Government Commitments

How does the government commitment τ^c_{IC} depend on the extent of firm commitments, as captured by μ? In general, when μ is higher (stronger firm commitments), the optimal government commitment with infinite credibility $\tau^c(\mu)$ falls. But with limited credibility, the actual tax τ^c_{IC} is non-monotone in μ, as shown in Figure 7. This non-monotonicity in how government commitments respond to firm commitments reflects two competing forces:

- In the region of weak firm commitments $\mu < \underline{\mu}$, the optimal credible commitment $\tau^c_{IC}(\mu, \kappa)$ is increasing in μ, hence government and firm commitments are complements in strength. The reason is that stronger firm commitments make it less costly for the government to tax carbon. As more firms commit, the government is able to move the tax $\tau^c_{IC}(\mu, \kappa)$ closer to its desired level $\tau^c(\mu)$.
- In the region of strong firm commitments $\mu \geq \underline{\mu}$, the dependence of τ^c_{IC} in μ is reversed, as the IC constraint (9) becomes slack and thus the tax is determined by the government's willigness to tax carbon, $\tau^c_{IC}(\mu, \kappa) = \tau^c(\mu)$, which is decreasing in the strength of firm commitments μ. As more firms commit, there is simply less need for carbon taxes to provide incentives to transition to green technology.

Overall, whether firm commitments make government commit to a higher or lower carbon tax depends on whether the government is constrained by its ability to tax carbon ($\mu < \underline{\mu}$) or by its willingness to tax carbon ($\mu \geq \underline{\mu}$). Yet our model highlights a different form of interaction, which is that firm commitments make government commitments more credible, in the following sense:

Proposition 7. *Consider two governments with different commitment abilities* κ *and* $\tilde{\kappa} < \kappa$. *For any* μ, *there exists* $\tilde{\mu} \geq \mu$ *such that* $W(\tau^c_{IC}(\tilde{\kappa}, \tilde{\mu}), 0, \tilde{\mu}) = W(\tau^c_{IC}(\kappa, \mu), 0, \mu)$.

This result states that a country with low government commitment power $\tilde{\kappa}$ can attain the same welfare as a country with high government credibility κ if firm commitments are stronger ($\tilde{\mu} \geq \mu$). When firms take on a larger share of the job, the government does not need to commit to such a high carbon tax, which is exactly what makes the government more credible. The link between firm commitments and government credibility arises because stronger firm commitments reduce the gap between the government's ex-ante optimal tax $\tau^c(\mu)$ and the ex-post optimal tax γ. Since the government does not need to distort taxes as much above γ to provide innovation incentives, its commitments become naturally more credible. This complementarity in credibility emerges even though firm and government commitments are substitutes in terms of their direct effects on emissions.

The effect of firm commitments on government credibility also means that an increase in μ has a particularly strong impact on welfare when the government has intermediate commitment ability κ, relative to governments with perfect commitment ($\kappa = \infty$) or no commitment at all ($\kappa = 0$). Figure A.5 shows welfare, as a deviation from the first-best welfare, as a function of the strength of firm commitments μ, for different values of the government's commitment ability κ. As firm commitments become stronger (μ increases), welfare increases faster with finite commitment ability κ than with infinite credibility $\kappa = \infty$: this also reflects the positive effect of firm commitments on government credibility.

Revisiting Firms' Incentives to Commit. Finally, we can revisit firms' and investors' incentives to commit, first discussed in Section 6.3, when government policies respond endogenously to the strength of firm commitments. Figure A.6 shows the profits of committers and non-committers as a function of μ, taking into account the response of the optimal government commitment $\tau^c_{IC}(\mu, \kappa)$. The dashed lines show the extreme case of no government commitment $\kappa = 0$ and thus no response of the carbon tax (i.e., Figure A.2). With some positive commitment ability κ, as in the solid lines, we see that incentives to commit can become much stronger in the region $\mu > \underline{\mu}$. We can interpret this result as saying that firm commitments may be limited at first, until they reach the critical mass $\underline{\mu}$ required to spur a strong complementarity with government policies.

8 Conclusion

The climate change transition is rightly seen in economics as requiring substitution away from technology that is carbon-emission intensive to one that is greener. While public policy (e.g., carbon taxes and green innovation subsidies) is clearly at the center of effecting this transition in a durable and timely manner, its unpredictability over political cycles and the inherent contract incompleteness is recognized as an important transition risk.

We show theoretically, and find empirical support for the mechanisms, that in such a second-best world, large firms and common institutional owners can play a significant role as agents of climate change. Even if these firms and investors are purely profit-maximizing, their commitments and actions as green innovators—as those of Stackelberg leaders—spur more innovation by other firms, which ultimately reduces their own cost of decarbonization. This positive externality, in turn, increases the credibility of government commitments to incentivize transition as they can achieve a given decarbonization with lower, and thus more credible, carbon taxes.

Our analysis yields three concrete policy implications for accelerating decarbonization.

Governments can achieve their environmental goals with lower carbon taxes as firm commitments increase. However, carbon taxes remain essential even with strong firm commitments, as they provide the underlying incentive for firms to decarbonize in the first place. Finally, regulators should recognize that some degree of coordination among firms through common ownership may actually facilitate the green transition, suggesting a potential tension with traditional antitrust concerns.

Several extensions of our work may be pursued in future work. Modeling the *dynamics* of firm and investor roles in the transition to Net Zero is important. The precise role of common ownership of firms by institutional investors in the face of legal antitrust challenges will be significant for empirical inquiry going forward. A richer model than ours would also allow for imperfect competition in product markets under common ownership, so as to analyze the net effect of common ownership. The theory could also be tested by examining how specific events such as the Inflation Reduction Act of 2022 have contributed to green innovation and the strategic timing considerations that have arisen given the political risks to its implementation.

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Online Appendix

A Additional tables and figures

A.1 Summary Statistics

Table A.1: Summary statistics of baseline regression sample.

Variables	(1) N	(2) mean	(3) sd	(4) min	(5) p10	(6) p50	(7) p90	(8) max
Firm Assets (bn)	3,560	20.1	130	0.00071	0.073	1.42	24.0	2,724
Log(Assets)	3,560	0.031	0.22	-0.72	-0.26	0.035	0.32	0.79
NZ Investor Ownership	3,560	0.044	0.11	0	0	0	0.25	0.73
NZ	3,560	0.090	0.29	0	0	0	0	1
DI	3,560	0.19	0.39	0	0	0	1	1

This table presents the summary statistics of the variables used in the regression analysis. The sample is the merged dataset of 13F Ownership and Compustat as of 2017. The Net Zero dummy NZ equals 1 if a firm committed during the period 2017 to 2023. The decarbonization investment dummy DI equals 1 if a firm reported decarbonization investments during 2012–2022.

Table A.2: Effect of Net Zero Investor Ownership on Decarbonization

	NZ		DI	
	(1)	(2)	(3)	(4)
NZ Investor Ownership	1.550***	1.590***	1.022***	1.043***
	(0.259)	(0.234)	(0.177)	(0.153)
Constant	0.023***	0.021*	0.146***	0.145***
	(0.005)	(0.010)	(0.027)	(0.007)
IndustryFE	No	Yes	No	Yes
Observations	3,560	3,560	3,560	3,560
Adj R^2	0.330	0.355	0.076	0.122

This table analyzes the relationship between firm ownership by Net Zero investors and decarbonization. Net Zero investors are defined as 13F investors belonging to one or more of the following climate alliances: Net Zero Asset Managers, Climate Action 100+, and the UN-convened Net Zero Asset Owner Alliance. 13F investor ownership data is from Backus et al. (2017), and total shares outstanding is sourced from CRSP, measured as of the end of 2017. The specification is: $Y_i = \beta \cdot \textit{NZ Investor Ownership}_i + \textit{const} + \gamma_i + \epsilon_i$, where i refers to a firm, Y is either the Net Zero dummy "NZ" or the decarbonization investment dummy "DI", and γ_i refers to industry fixed effects. Standard errors, clustered at the industry level, are reported in parentheses below the coefficients. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

A.2 Figures

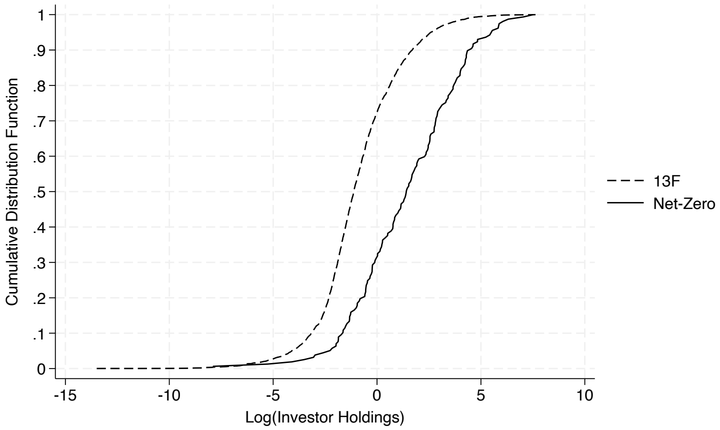

Figure A.1: Cumulative distribution function of institutional investor size (by assets under management based on the 13F filings) for “Net Zero investors” (solid line) and all 13F investors (dashed line)

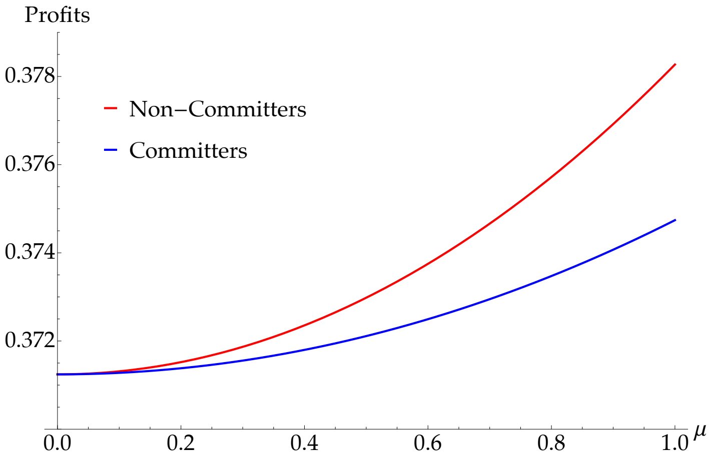

Figure A.2: Equilibrium firm profits Π for committers and non-committers as a function of coalition size μ. Here $\bar{\tau} = \gamma$ and $\sigma = 0$.

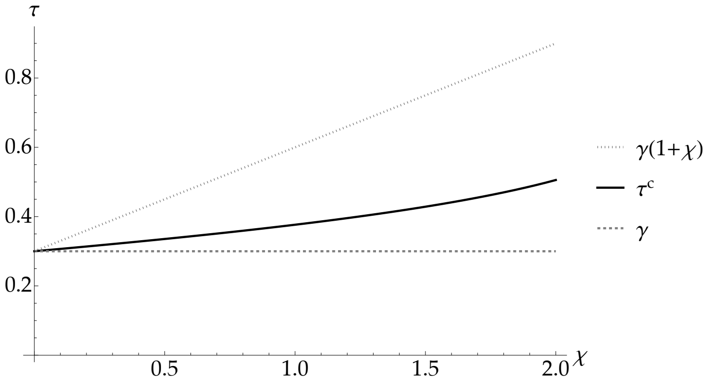

Figure A.3: Optimal carbon tax under full commitment as a function of χ, without firm commitments ($\mu = 0$).

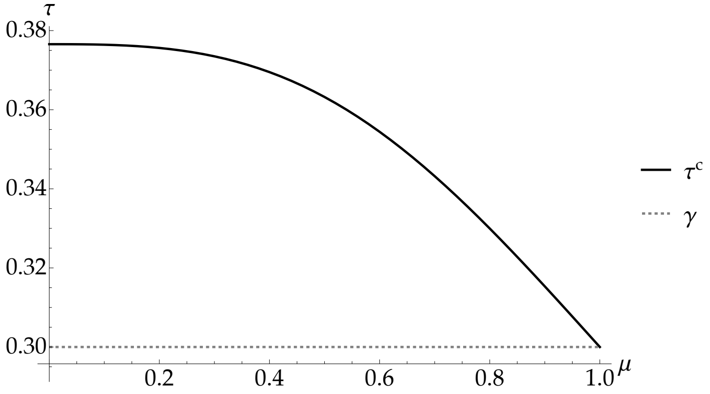

Figure A.4: Optimal carbon tax under full commitment as a function of firm commitments μ.

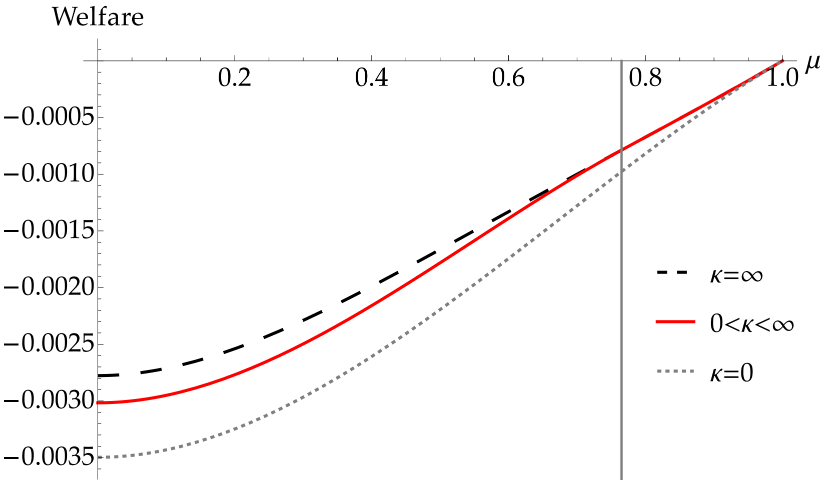

Figure A.5: Ex-ante welfare (measured as deviation from first-best welfare) as a function of μ when varying firm and government commitment power. The vertical line denotes $\underline{\mu}$.

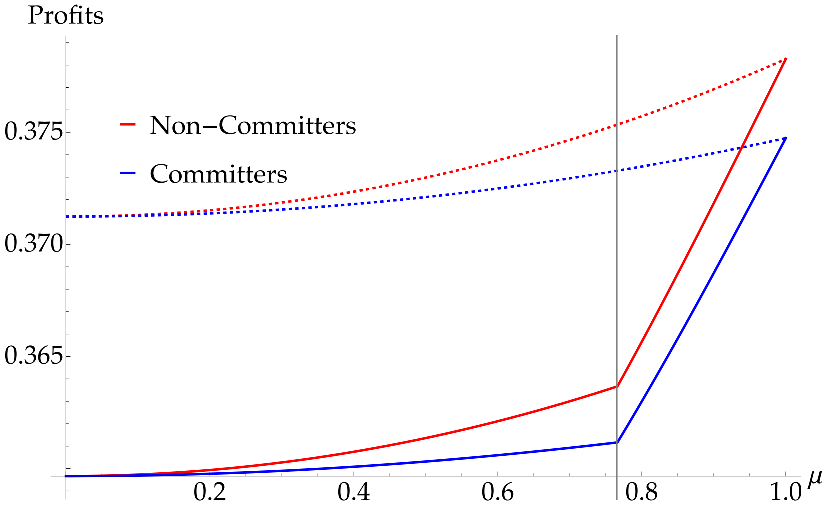

Figure A.6: Equilibrium firm profits Π for committers and non-committers as a function of coalition size μ when the carbon tax is $\tau^{c}_{IC}(\mu, \kappa)$ with $\kappa > 0$. The dashed lines show the case without any government commitment, $\kappa = 0$, and thus $\tau = \gamma$.

B Proofs

B.1 Proof of Proposition 2

The Lagrangian is

$$f(k) - k - C(\Delta) - \gamma\left[\theta_0 - \Delta(1+\chi)\right]k + \lambda\left\{1 + (\theta_0 - \Delta(1+\chi))\bar{\tau} - f'(k)\right\}$$

and the government's optimality conditions are

$$f'(k) = 1 + \gamma\theta + \lambda f''(k)$$

hence

$$-\lambda f''(k) = (\gamma - \bar{\tau})\theta$$

and if $\lambda > 0$

$$\begin{aligned} C'(\Delta) &= (1+\chi)\left[\gamma k - \lambda\bar{\tau}\right] \\ &= \bar{\tau}k + k(\gamma - \bar{\tau}) + \chi k\gamma + (1+\chi)\frac{(\gamma-\bar{\tau})\theta}{f''(k)}\bar{\tau} \\ &= \bar{\tau}k + \chi k\gamma + (\gamma - \bar{\tau})\left\{k + \frac{\theta(1+\chi)\bar{\tau}}{f''(k)}\right\} \end{aligned}$$

The planner uses a subsidy

$$\sigma = \chi k\gamma + (\gamma - \bar{\tau})\left(k + \frac{\theta(1+\chi)\bar{\tau}}{f''(k)}\right)$$

which combines the standard subsidy and an extra term (positive if $\bar{\tau}$ is low enough) that replaces the carbon tax.

With our functional forms,

$$\begin{aligned} c\Delta &= \bar{\tau}k + k(\gamma - \bar{\tau}) + \chi k\gamma - (1+\chi)\frac{(\gamma-\bar{\tau})(\theta_0 - (1+\chi)\Delta)}{a}\bar{\tau} \\ k &= a - \bar{\tau}(\theta_0 - (1+\chi)\Delta) \end{aligned}$$

$\theta = \theta_0 - (1+\chi)\Delta$ and $\theta = \frac{a-k}{\bar{\tau}}$ hence

$$\begin{aligned}\frac{c}{1+\chi}(\theta_0 - \frac{a-k}{\bar{\tau}}) &= \bar{\tau}k + k(\gamma - \bar{\tau}) + \chi k\gamma - (1+\chi)\frac{(\gamma-\bar{\tau})}{a}(a-k) \\ \frac{c}{1+\chi}(\theta_0 - \frac{a}{\bar{\tau}}) + (1+\chi)(\gamma-\bar{\tau}) &= k\left\{\gamma(1+\chi) - \frac{c}{1+\chi}\frac{1}{\bar{\tau}} + (1+\chi)\frac{(\gamma-\bar{\tau})}{a}\right\}\end{aligned}$$

implies

$$\begin{aligned}k(\bar{\tau}) &= \frac{(\bar{\tau}\theta_0 - a) + (1+\chi)^2\bar{\tau}/c(\gamma-\bar{\tau})}{\gamma\bar{\tau}/c(1+\chi)^2 - 1 + (1+\chi)^2\frac{\bar{\tau}(\gamma-\bar{\tau})}{ac}} \\ &= \frac{a - \bar{\tau}\theta_0 - (1+\chi)^2\frac{\bar{\tau}}{c}(\gamma-\bar{\tau})}{1 - \gamma\frac{\bar{\tau}}{c}(1+\chi)^2 - (1+\chi)^2\frac{\bar{\tau}(\gamma-\bar{\tau})}{ac}}\end{aligned}$$

Therefore

$$\sigma^*(\bar{\tau}) = \chi k(\bar{\tau})\gamma + (\gamma-\bar{\tau})\left(k(\bar{\tau})\left[1 + \frac{1+\chi}{a}\right] - (1+\chi)\right)$$

Note that if $\bar{\tau} = \gamma$ we recover the first-best level: $k = \frac{a-\theta_0\gamma}{1-\frac{\gamma^2}{c}(1+\chi)^2} = k^*$.

Then

$$\Delta = \frac{\theta_0 - \theta}{1+\chi} = \frac{\theta_0 - \frac{a-k}{\bar{\tau}}}{(1+\chi)}.$$

The emission intensity attained by this policy is

$$\theta = \frac{a - \frac{a-\bar{\tau}\theta_0-(1+\chi)^2\frac{\bar{\tau}}{c}(\gamma-\bar{\tau})}{1-\gamma\frac{\bar{\tau}}{c}(1+\chi)^2-(1+\chi)^2\frac{\bar{\tau}(\gamma-\bar{\tau})}{ac}}}{\bar{\tau}}.$$

B.2 Proof of Proposition 3

With our functional forms,

$$c\Delta^l = \tau\left[a - \tau(\theta_0^l - \Delta^l(1+\chi\mu) - (1-\mu)\chi\frac{\tau\left(a - \tau\theta_0^s + \chi\tau\mu\Delta^l\right)}{c - \tau^2(1+\chi(1-\mu))})\right]\left[1 + \chi\left(\mu + \frac{\tau^2\chi\mu(1-\mu)}{c-\tau^2(1+\chi(1-\mu))}\right)\right] \tag{A.1}$$

$$\left[\frac{c}{1+\chi\left(\mu+\frac{\tau^2\chi\mu(1-\mu)}{c-\tau^2(1+\chi(1-\mu))}\right)}-\tau^2(1+\chi\mu)\right]\Delta^l=\tau\left[a-\tau(\theta_0^l-(1-\mu)\chi\frac{\tau\left(a-\tau\theta_0^s+\chi\tau\mu\Delta^l\right)}{c-\tau^2(1+\chi(1-\mu))})\right]$$

$$\Delta^l(\tau)=\tau\cdot\frac{a-\tau\theta_0^l+\tau^2(1-\mu)\chi\frac{a-\tau\theta_0^s}{c-\tau^2(1+\chi(1-\mu))}}{\frac{c}{1+\chi\mu\left(1+\frac{\tau^2\chi(1-\mu)}{c-\tau^2(1+\chi(1-\mu))}\right)}-\tau^2(1+\chi\mu)+\frac{\tau^3\chi^2\mu(1-\mu)}{c-\tau^2(1+\chi(1-\mu))}}$$

and therefore

$$\begin{aligned}
k^l &= \frac{c\Delta^l}{\tau\left[1+\chi\left(\mu+(1-\mu)\frac{\partial\Delta^s}{\partial\Delta^l}\right)\right]}\\
&= \frac{c\Delta^l}{\tau\left[1+\chi\left(\mu+(1-\mu)\frac{\tau^2\chi\mu}{c-\tau^2(1+\chi(1-\mu))}\right)\right]}\\
&= \frac{c}{1+\chi\left(\mu+(1-\mu)\frac{\tau^2\chi\mu}{c-\tau^2(1+\chi(1-\mu))}\right)}\times\frac{a-\tau\theta_0^l+\tau^2(1-\mu)\chi\frac{a-\tau\theta_0^s}{c-\tau^2(1+\chi(1-\mu))}}{\frac{c}{1+\chi\left(\mu+\frac{\tau^2\chi\mu(1-\mu)}{c-\tau^2(1+\chi(1-\mu))}\right)}-\tau^2(1+\chi\mu)+\frac{\tau^3\chi^2\mu(1-\mu)}{c-\tau^2(1+\chi(1-\mu))}}
\end{aligned}$$

B.3 Proof of Proposition 4

Suppose that $\mu = 1$ hence the entire private sector acts as a single coalition. In this case the optimal firm commitment solves

$$\max_{\Delta,k} f(k)-k-C(\Delta)+\sigma\Delta-\bar{\tau}\left[\theta_0-(1+\chi)\Delta\right]k.$$

The firm's two optimality conditions are

$$f'(k)=1+\bar{\tau}\left[\theta_0-(1+\chi)\Delta\right], \tag{A.2}$$

$$C'(\Delta)=\sigma+\bar{\tau}(1+\chi)k. \tag{A.3}$$

Notice that relative to the case of no firm commitments ($\mu = 0$) studied in Section 5.2, the only difference is that the optimality condition with respect to Δ is (A.3) instead of

$$C'(\Delta)=\sigma+\bar{\tau}k.$$

However, once we allow the government to optimize freely over the innovation subsidy σ, the distinction becomes irrelevant: by increasing σ the government can always replicate what would be achieved by firm commitments. As a result

$$\max_{\sigma} W(\bar{\tau}, \sigma, 1) = \max_{\sigma} W\left(\bar{\tau}, \sigma, 0\right).$$

The same argument shows that for any coalition size $\mu \in [0, 1]$, the solution to a fictitious relaxed problem that allows the government to set different innovation subsidies for committers and non-committers is also equal to $\max_{\sigma} W(\bar{\tau}, \sigma, 0)$. Therefore the maximum welfare when the innovation subsidy cannot differ across firms is weakly lower.

B.4 Proof of Proposition 5

We start with the first inequality

$$\max_{\sigma} W(0, \sigma, 0) \leq W(\gamma, 0, 0).$$

Denote $\sigma^*(0)$ the optimal innovation subsidy with a zero carbon tax, that is, $\max_{\sigma} W(0, \sigma, 0) = W(0, \sigma^*(0), 0)$. Denote $\Delta(\sigma, \tau)$ the innovation given a subsidy σ and a carbon tax τ. Then the innovation $\Delta(\sigma^*(0), 0)$ under the optimal subsidy but no tax solves

$$\begin{aligned} &\max_{\Delta} f(k) - k - C(\Delta) - \gamma(\theta_0 - (1+\chi)\Delta)k \\ &\text{s.t. } f'(k) = 1 \end{aligned}$$

or

$$C'(\Delta) = \gamma(1+\chi) f'^{-1}(1)$$

We have

$$\begin{aligned} \max_{\sigma} W(0, \sigma, \mu) &= \max_{\sigma} W(0, \sigma, 0) \\ &= \underbrace{f(a) - a - \gamma\theta_0 a}_{W(0,0,0)} + \frac{1}{2}\left(1+\chi\right)^2 \frac{\gamma^2 a^2}{c} \\ &= \frac{a^2}{2} - \gamma\theta_0 a + \frac{1}{2}\left(1+\chi\right)^2 \frac{\gamma^2 a^2}{c} \end{aligned}$$

whereas given $k = (a - \gamma\theta_0)\frac{c}{c-\gamma^2(1+\chi)}$ and $\Delta = \frac{\gamma(a-\gamma\theta_0)}{c-\gamma^2(1+\chi)}$ we have

$$W(\gamma, 0, 0) = \frac{c\left(c-\gamma^2\right)\left(a-\gamma\theta_0\right)^2}{2\left(c-\gamma^2(1+\chi)\right)^2}.$$

Inequality (4) then follows from equalizing $\max_\sigma W(0, \sigma, 0)$ and $W(\gamma, 0, 0)$ and noting that for $\chi = 0$ we always have

$$W(\gamma, 0, 0) = \frac{c(a-\gamma\theta_0)^2}{2\left(c-\gamma^2\right)} \geq \frac{a^2}{2} - \gamma\theta_0 a + \frac{1}{2}\frac{\gamma^2 a^2}{c} = \max_\sigma W(0, \sigma, 0).$$

Then we know that

$$\begin{aligned} W(0, \sigma^*(0), 0) &\leq \max_k f(k) - k - C(\Delta(\sigma^*(0), 0)) - \gamma(\theta_0 - (1+\chi)\Delta(\sigma^*(0), 0))k \\ &\leq \max_k f(k) - k - C(\Delta(0, \gamma)) - \gamma(\theta_0 - (1+\chi)\Delta(0, \gamma))k \\ &\leq \max_k f(k) - k - C(\Delta^{FB}) - \gamma(\theta_0 - (1+\chi)\Delta^{FB})k \end{aligned}$$

The second inequality in the Proposition

$$W(\gamma, 0, 0) \leq W(\gamma, 0, \mu)$$

follows from the fact that firm commitments increase welfare since firms within the coalition could always choose the same k and Δ as under $\mu = 0$.

The third inequality in the Proposition

$$W(\gamma, 0, \mu) \leq W(\gamma, 0, 1)$$

follows from the fact that when $\mu = 1$ firm commitments achieve the first best, i.e., $W(\gamma, 0, 1) = W^{FB}$.

B.5 Proof of Proposition 6

The corresponding Lagrangian is

$$f(k) - k - C(\Delta) - \mathcal{L}(Z_0 + [\theta_0 - \Delta(1+\chi)]k) + \lambda\left\{1 + \frac{C'(\Delta)}{k}(\theta_0 - \Delta(1+\chi)) - f'(k)\right\}$$

hence the government's first-order optimality conditions are

$$f'(k) - 1 - \gamma\theta - \frac{\lambda}{k}\overbrace{\left[\frac{C'(\Delta)}{k}\theta + kf''(k)\right]}^{=f'(k)-1+kf''(k)} = 0$$
$$-C'(\Delta) + \gamma(1+\chi)k + \lambda\left[\frac{C''(\Delta)}{k}\theta - \frac{C'(\Delta)}{k}(1+\chi)\right] = 0$$

which can be rewritten in terms of the tax $\tau^c = C'(\Delta)/k = \frac{1}{\theta}(f'(k)-1)$ as

$$f'(k) = 1 + \gamma\theta + \frac{\lambda}{k}\left[\theta\tau^c + kf''(k)\right]$$
$$\frac{\lambda}{k} = \frac{1}{\frac{C''(\Delta)}{k}\theta - \tau^c(1+\chi)}\left(\tau^c - \gamma(1+\chi)\right)$$

If $\chi = 0$ the solution is trivial: $\tau^c = \gamma$, $\lambda = 0$. This reiterates that commitments are not needed to achieve the first best when there are no innovation externalities.

Suppose then that $\chi > 0$. Our functional forms imply $f'(k) - 1 + kf''(k) = a - 2k$ hence

$$f'(k) = 1 + \gamma\theta + \frac{\lambda}{k}\left[a - 2k\right]$$

The second FOC rewrites as
$$\frac{\lambda}{k} = \frac{\tau^c - \gamma(1+\chi)}{\theta\frac{c}{k} - \tau^c(1+\chi)}$$

hence

$$f'(k) = 1 + \tau^c\theta = 1 + \gamma\theta + (a-2k)\frac{\tau^c - \gamma(1+\chi)}{\theta\frac{c}{k} - \tau^c(1+\chi)}$$

which leads to

$$(\tau^c - \gamma)\theta = (a-2k)\,\frac{\tau^c - \gamma(1+\chi)}{\theta\frac{c}{k} - \tau^c(1+\chi)}$$
$$\frac{\tau^c - \gamma}{\tau^c - \gamma(1+\chi)} = \frac{\tau^c k}{a-k}\,\frac{a-2k}{c\theta_0 - 2\tau^c k(1+\chi)}$$

where we used $k = a - \tau^c\theta$, $\Delta = \tau^c k/c$, and $\theta = \theta_0 - \Delta(1+\chi)$, which also implies

$$k(\tau^c) = \frac{a - \tau^c\theta_0}{1 - \frac{(\tau^c)^2}{c}(1+\chi)}.$$

If $\tau^c - \gamma$ and $\tau^c - \gamma(1+\chi)$ have opposite signs, then the optimal commitment τ^c satisfies $\tau^c \in [\gamma, \gamma(1+\chi)]$.

Since $a > k(\tau^c)$ for any $\tau^c \geq 0$ by Assumption 1, we have that $\tau^c - \gamma$ and $\tau^c - \gamma(1+\chi)$ have opposite signs if

$$\frac{a - 2k(\tau^c)}{\frac{c\theta_0}{\tau^c(1+\chi)} - 2k(\tau^c)} < 0$$

when evaluated at $\tau^c = \gamma$, which is equivalent to

$$\frac{c\left[a - 2\gamma\theta_0\right] + a\gamma^2(1+\chi)}{c\theta_0 - \gamma(1+\chi)(2a - \gamma\theta_0)} > 0.$$

The denominator is positive by Assumption 1 since

$$c > \gamma(1+\chi)^2(2a/\theta_0 - \gamma) > \gamma(1+\chi)(2a/\theta_0 - \gamma).$$

The numerator is positive if $a > 2\gamma\theta_0$.

C Green and Brown Technologies

We outline a mapping between our model and an alternative model, closer to some models in the literature such as Acemoglu et al. (2012), in which firms have a choice between two technologies, "green" and "brown", such that the brown technology has a higher productivity but also higher emission intensity. For simplicity we abstract from technological spillovers here, setting $\chi = 0$, but a similar mapping can be written with $\chi > 0$.

In our model we can rewrite production net of costs of innovation as

$$F(k, \Delta) \equiv f(k) - k - C(\Delta). \tag{A.4}$$

If we interpret Δ as how green technology is, $F_\Delta < 0$ captures the effective productivity advantage of brown technology (i.e., it does not require the firm to pay the cost C). Firms subject to a tax τ and a subsidy σ maximize

$$F(k, \Delta) - \tau\left[\theta_0 - \Delta\right]k + \sigma\Delta$$

Consider now an alternative model with an explicit choice between green and brown technologies. Suppose there are two production functions for green and brown intermediate inputs:

$$y_g = A_g k_g$$
$$y_b = A_b k_b$$

with $A_g < A_b$. Production using brown technology emits $\theta_0 k_b$, whereas green technology emits $\theta_g k_g$ with $\theta_g < \theta_b$; we normalize $\theta_g = \theta_0 - 1$. The final good is given by aggregating the green and brown inputs using an aggregator G

$$Y = G(y_g, y_b)$$

which captures the substitutability between green and brown inputs; for instance, if they are perfectly substitutable then $\frac{\partial G}{\partial y_b} = \frac{\partial G}{\partial y_g}$. Firms subject to a carbon tax τ per unit of emissions and a subsidy to using the green technology $\sigma \cdot \frac{k_g}{k_g + k_b}$ solve

$$\max_{k_g, k_b} G(A_g k_g, A_b k_b) - \tau(\theta_g k_g + \theta_0 k_b) + \sigma \frac{k_g}{k_g + k_b}$$

First abstracting from technological externalities/spillovers, we can change variables to rewrite this problem exactly as in our formulation (A.4):

$$\max_{k, \Delta} F(k, \Delta) - \tau \left(\theta_0 - \Delta\right) k + \sigma \Delta$$

where

$$k \equiv k_b + k_g$$
$$\Delta \equiv k_g / k$$
$$F(k, \Delta) \equiv G(A_g \Delta \cdot k, A_b k(1 - \Delta))$$

Now

$$F_\Delta = -k \left[A_b \frac{\partial G}{\partial y_b} - A_g \frac{\partial G}{\partial y_g} \right]$$

Therefore if the technologies are sufficiently substitutable (so $\frac{\partial G}{\partial y_b} \approx \frac{\partial G}{\partial y_g}$) and green technology is less productive ($A_g < A_b$) as we assumed, we obtain $F_\Delta < 0$ as before.

In this context, the technological externality or spillover corresponds to a positive effect of the average adoption of green technology $\bar{\Delta} = \int_i \Delta_i di$ on the productivity A_g, so that:

$$F(k, \Delta, \bar{\Delta}) \equiv G(A_g(\bar{\Delta})\Delta \cdot k, A_b k(1 - \Delta)).$$