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Firms' and States' Responses to Laxer Environmental Standards

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Abstract

On June 1, 2017, President Trump announced the United States' withdrawal from the Paris agreement on climate change. Despite this decision, American firms continued investing in low-carbon technologies and some states committed to tougher environmental standards. To understand this apparent paradox, this paper studies how a weakening of environmental standards affects the behavior of profit-maximizing firms. It finds that a relaxation of emission standards (i) may increase firms' incentives to adopt clean technologies, but not to pollute less; (ii) may negatively affect industry profitability if it is perceived as temporary; and, when this is the case, (iii) the unilateral adoption of stricter standards by large states may increase the expected profitability of every firm.

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Firms'and States'Responses to Laxer Environmental Standards*

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1 Introduction

President Donald Trump's announcement on June 1, 2017 that the United States would withdraw from the Paris agreement was a setback to the global effort to mitigate climate change. Curtailing greenhouse gas (GHG) emissions is a global public good that, in the absence of public action, will be underprovided by the private sector. Furthermore, the U.S. is a large economy, so increased GHG emissions by American firms in the wake of relaxed environmental regulations could accelerate climate change further.

Against this background, the International Energy Agency's (2018) report on Global Energy and CO2 showed that the share of renewables in electricity generation reached a record level of 17 percent in the U.S. The major oil companies, including ExxonMobil, have continued to invest in low-carbon technologies. Moreover, in September 2018, the then-governor of California (the largest U.S. state), Jerry Brown, signed an executive order committing the state to being carbon-neutral by 2045. As Hultman and Bodnar (2018) put it, "Trump tried to kill the Paris agreement, but the effect has been the opposite."

These actions may be due to the public-spirited behavior of firms and state governments. We show in this paper that they could also be the result of profit-maximizing behavior and successful lobbying efforts of firms in the face of weaker environmental standards. First, we find that a decision to relax emission standards could increase firms' incentives to adopt clean technologies. However, the overall level of emissions may increase, since the cleaner technologies enable firms to produce more. Secondly, industry profitability may be reduced by the weakening of environmental standards if there is a chance that the decision will be reversed later. In this case, firms in large states have an incentive to lobby state governments to implement environmental standards that are stricter than the federal ones. If the chances of policy reversal go down, the state's regulations will approach those of the federal government. In short, while the seemingly "green" actions following the U.S.'s withdrawal from the Paris agreement can be interpreted in terms of profit-maximizing behavior of firms, there is no guarantee that they will translate into lower emissions.

Of course, we are not the first to study how emission standards affect firms' technology choices.[1] Van der Zwaan et al. (2002) introduce endogenous technological change in a macroeconomic model of climate change, and argue that the development of carbon-free technologies plays a critical role in carbon reduction and allows for lower optimal carbon taxes. Acemoglu et al. (2012) show how temporary environmental regulations–a combination of research subsidies and carbon taxes–can redirect technical change toward clean technologies and avoid environmental disasters. Acemoglu and Rafey (2018) study the effects of geoengineering in a model in which the government cannot commit to future policies. They show that, when this is the case, the anticipated reduction in future taxes may discourage firms from adopting cleaner technology.[2]

Particularly relevant to our analysis is Krass et al. (2013) who look at firms' reaction to environmental regulations (tax, subsidy, and rebate levels) and show that increasing carbon taxes does not monotonically increase firms' adoption of green technology. The intuition is that when taxes are very high, firms' production quantity can be so small that switching to cleaner technology generates insufficient additional profit to offset the fixed cost of adopting the technology. Perino and Requate (2012) also show that the relationship between policy stringency and the rate of technology adoption is an inverted U-shape for a broad class of technologies. Our model shares such features.

On the empirical side, Aghion et al. (2016) show that, in the auto industry, firms are more likely to innovate in clean technologies if they are confronted with higher tax-inclusive fuel prices. Yang et al. (2012) examine whether stringent environmental regulations induce more R&D and promote productivity in Taiwan, China's manufacturing industry and find that stricter regulations are positively related to R&D expenditures and industrial productivity.

[1] See Jaffe, Newell, and Stavins (2002), Löschel (2002), and Requate (2005) for an overview.

[2] The idea that the possibility of a policy reversal may turn detrimental an otherwise sensible reform was first discussed by Rodrik (1991).

2 The Model

We consider an economy where a continuum of firms (of mass one) produce a final good, which is sold in the world market at a price p, which we normalize to one. Denoting output by x, and assuming a convex cost function $c(x) = \frac{1}{2}x^2$, the profits of firm i at time t are given by

$$\pi_{it}(x_{it}) = x_{it} - \frac{x_{it}^2}{2}. \tag{1}$$

Production causes carbon emissions, e_{it}, which are proportional to output levels and depend on the technology adopted by the firm. More precisely, we assume that $e_{it} = k_j x_{it}$, $j \in \{d, c\}$, where d stands for dirty, and c for clean technology,[3] and $k_d > k_c$. The cost of adopting the clean technology, Γ_i, varies across firms and we let Γ_i be uniformly distributed over the interval $[\underline{\Gamma}_i,\overline{\Gamma}_i]$. We further assume that there are no private costs associated with emissions, and that there is no cap and trade system that allows firms to sell "pollution rights." Hence, firms adopt the clean technology only if it yields higher profits. The timing of the model is as follows:

- At time $t = -1$
  - The government announces a carbon emission limit ω_t^{BT}, for $t = \{0,1\}$, that all firms should abide by. The limit is consistent with a carbon emission target $\overline{\Omega}$ that is exogenously decided (e.g., as part of an international agreement);
  - Firms announce whether they are considering adopting a (costly) clean technology in period 0 or not (cheap talk).
- At time $t = 0$
  - Unexpectedly, a new government gains power and tweets a new carbon emission cap ω_t^T, which is not consistent with $\overline{\Omega}$, that is, $\omega_t^T > \omega_t^{BT}$.
  - Firms revise their plans of whether to adopt the clean technology or not;
  - Firms make production plans.
- At time $t = 1$
  - With probability $1 - \mu$, the current government is replaced by a new government that sets a carbon emission limit ω^{AT} that is consistent with $\overline{\Omega}$;
  - If this happens, firms adjust their production plans, but not the technology that is already set, according to the new limit.

2.1 Before Transition ($t = -1$)

Recall that the government is committed to cap the sum of total carbon emissions in periods 0 and 1 to $\overline{\Omega}$. Absent carbon emission limits, firms have no incentives to adopt the clean technology and they produce

$$\widehat{x_t}^* = \arg\max_x \pi_t(x_t) = 1. \tag{2}$$

Denoting total "unregulated" carbon emissions by $\widetilde{\Omega}$, we have that $\widetilde{\Omega} = k_d(\widehat{x}_0^* + \widehat{x}_1^*) = 2k_d$; no firm will upgrade to the clean technology because it is costly (see below). If a limit ω_t is put in place, the output of a firm of type j is given by

$$x_{jt}^*(\omega_t) = Min\{1, \frac{\omega_t}{k_j}\}. \tag{3}$$

[3] For real world examples, one could look at industries where emissions are mostly associated with the shipment of the final good and firms can either use fuel efficient or fuel inefficient means of transportation.

To simplify the analysis, we consider situations in which the government is committed to a target $\overline{\Omega}$ that is stringent enough. More precisely, we assume that

$$\overline{\Omega} < 2k_c, \tag{A.1}$$

so that, even if all firms switched to the clean technology, a carbon limit will still be needed to meet the target.[4] Notice that this implies that $k_c > \omega_t$. We also assume that the government cannot verify the technology adopted by the firms and cannot impose a limit that is contingent on the technology adopted. Under such assumptions, and assuming no discounting, total profits of a firm of type j are given by

$$\pi_j = \pi_{j0}(\frac{\omega_0}{k_j}) + \pi_{j1}(\frac{\omega_1}{k_j}). \tag{4}$$

We further assume that the government is benevolent, and that it chooses ω_0 and ω_1 to meet the target at the smallest cost for the firms. In our set-up, where all firms share the same concave profit function, the least costly carbon limits that are consistent with $\overline{\Omega}$ are necessarily

$$\omega^{*BT} = \omega_0^{*BT} = \omega_1^{*BT} = \overline{\Omega}/2. \tag{5}$$

Substituting now (5) into (4), we can express the variable profits of clean and dirty firms as

$$\pi_c^{BT} = \frac{(4k_c - \overline{\Omega})\overline{\Omega}}{4k_c^2}, \tag{6}$$

$$\pi_d^{BT} = \frac{(4k_d - \overline{\Omega})\overline{\Omega}}{4k_d^2}, \tag{7}$$

respectively. Hence, a firm adopts the clean technology iff the cost Γ_i of adopting the clean technology for firm i is low enough, that is,

$$\Gamma_i < \pi_c^{BT} - \pi_d^{BT} = \frac{(k_d - k_c)\overline{\Omega}(4k_ck_d - (k_c + k_d)\overline{\Omega})}{4k_c^2k_d^2} \equiv \Gamma^{BT}, \tag{8}$$

and the fraction γ^{BT} of firms that adopt the clean technology is given by

$$\gamma^{BT} = \begin{cases} 0, & \text{if } \Gamma^{BT} < \underline{\Gamma}_i; \\ \frac{\Gamma^{BT} - \underline{\Gamma}_i}{\overline{\Gamma}_i - \underline{\Gamma}_i}, & \text{if } \Gamma^{BT} \in (\overline{\Gamma}_i,\ \underline{\Gamma}_i); \\ 1, & \text{if } \Gamma^{BT} > \overline{\Gamma}_i. \end{cases} \tag{9}$$

2.2 Transition

We now consider a situation where a new government, unexpectedly voted into office in period 0, decides that the carbon target $\overline{\Omega}$ is no more binding and that carbon emission limits can be increased. How would such a policy affect firms' decisions to invest in clean technologies and, ultimately, their profitability?

To answer this, assume that the government decides to depart from $\overline{\Omega}$ and sets a new emission cap $\overline{\Omega}^T$ such that

$$\overline{\Omega}^T = \overline{\Omega} + z. \tag{10}$$

For the sake of simplicity, and recognizing that it is often difficult to completely rewrite a regulatory framework, we start by considering the effect of small changes in regulation. Hence, we assume that

$$z < 2k_c - \overline{\Omega}, \tag{A.2}$$

[4] Such an assumption greatly simplifies the analysis ensuring that the emissions of firms adopting clean and dirty technologies are the same. When this is the case, the limit that is consistent with the target does not depend on the fraction γ (see below) of firms that adopt the clean technology. We will relax this assumption in section 5.

so that, even if all firms switched to the clean technology, a carbon limit will still be needed to meet the revised target. Again, if the government continues choosing ω_0 and ω_1 to meet the target at the smallest cost for the firms,[5] we have that

$$\omega^{*T} = \omega_0^{*T} = \omega_1^{*T} = \frac{\overline{\Omega} + z}{2}. \tag{11}$$

As we already mentioned, the change in the regulatory framework can be temporary. Indeed, in period 1, with probability $(1-\mu)$, the government will be voted out of office. When this happens, the new government sets an emission limit ω^{AT} that restores the original commitment of capping total emissions at $\overline{\Omega}$. Of course, such a limit is stricter than ω^{*BT} because it has to compensate for the increase in period 0's emissions. We thus have that

$$\omega^{AT} = \overline{\Omega} - \omega^{T} = \frac{\overline{\Omega} - z}{2}, \tag{12}$$

and we work under the assumption that

$$z < \overline{\Omega}, \tag{A.3}$$

so that $\omega^{AT} > 0$. The expected variable profits of a firm of type j are then given by

$$E[\pi_j] = (1+\mu)\pi_j(\frac{\omega^T}{k_j}) + (1-\mu)\pi_j(\frac{\omega^{AT}}{k_j}), \tag{13}$$

where E is the expectation operator and

$$\pi_j(\frac{\omega^T}{k_j}) = \frac{(4k_j - \overline{\Omega} - z)(\overline{\Omega} + z)}{8k_j^2}, \tag{14}$$

$$\pi_j(\frac{\omega^{*AT}}{k_j}) = \frac{(4k_j - \overline{\Omega} + z)(\overline{\Omega} - z)}{8k_j^2}. \tag{15}$$

Using these expressions, (13) can be written as

$$E[\pi_j] = \frac{4k_j(\overline{\Omega} + \mu z) - \overline{\Omega}^2 - 2\mu\overline{\Omega}z - z^2}{2k_j^2}. \tag{16}$$

Hence, firm i will adopt the clean technology iff

$$\Gamma_i < E[\pi_c] - E[\pi_d] = \frac{(k_d - k_c)(\overline{\Omega}(4k_ck_d - (k_d + k_c)\overline{\Omega}) - 2\mu z((k_d + k_c)\overline{\Omega} - 2k_ck_d) - (k_d + k_c)z^2)}{4k_c^2k_d^2} \equiv \Gamma^T, \tag{17}$$

and the fraction γ^T of firms that adopts the clean technology is given by

$$\gamma^T = \begin{cases} 0, & \text{if } \Gamma^T < \underline{\Gamma}_i; \\ \frac{\Gamma^T - \underline{\Gamma}_i}{\overline{\Gamma}_i - \underline{\Gamma}_i}, & \text{if } \Gamma^T \in (\overline{\Gamma}_i,\ \underline{\Gamma}_i); \\ 1, & \text{if } \Gamma^T > \overline{\Gamma}_i. \end{cases} \tag{18}$$

3 Firms' Responses

In the remaining of the paper, we discuss how a relaxation in the regulatory standards is likely to affect firms' incentives to switch from the dirty to the clean technology and, ultimately, their profitability. We also discuss whether, and under which circumstances, a subset of firms may find it to be in their self interest to abide by standards that are stricter than the prevailing ones.

[5] In setting its policies, the government assumes that it will remain in power in the next period with probability one.

3.1 Cleaner or dirtier?

In order to assess how a relaxation in environmental standards may affect firms' decisions regarding technology adoption, we focus our attention on the interesting case in which $\Gamma^{BT} \in (\underline{\Gamma}_i, \overline{\Gamma}_i)$ and thus a fraction $\gamma^{BT} > 0$ of firms would be interested in adopting the clean technology before the change in regulation occurs. We now ask the question of whether the relaxation in the emission cap will increase or decrease the number of firms that decide to switch to the clean technology. Our main finding is that:

Proposition 1 *Iff the original carbon emission target $\overline{\Omega}$ is stringent enough, $\overline{\Omega} < \widehat{\Omega} \equiv \frac{2k_c k_d}{k_c + k_d}$, a small increase in the emission cap z, $z < \widetilde{z} \equiv \mu(\widehat{\Omega} - \overline{\Omega})$, induces more firms to adopt the clean technology; a large increase has the opposite effect. The higher is the probability μ that standards are not reversed in the next period, the larger is $\widetilde{z}$.*

Proof: In Appendix.

Notice that Proposition 1 does not mean that a relaxation in the emission cap, by inducing firms to adopt a cleaner technology, is good for the environment. In our set-up, the total amount of emissions is independent of the choice of the technology and higher caps necessarily mean more emissions. The reason why firms may be induced to switch to the clean technology is that, when $\overline{\Omega} < \widehat{\Omega}$, an increase in the emission limits increases the profits associated with the use of the clean technology more than those associated with the dirty one.[6] This follows directly from the concavity of the profit function and the linear cost of adopting the clean technology.[7] In addition, the shift in technology adoption induced by the relaxation of the emission standards is magnified, in either direction, if the probability μ that the government remains in power increases, so that policy reversals become less likely.[8]

Figure 1 below, illustrates the different forces at play. If emission standards are pretty tight to start with, $\overline{\Omega} = \overline{\Omega}_a$, their relaxation by an amount z increases the profits of clean firms (in green) more than those of the dirty ones (in brown). This induces more firms to adopt the clean technology and the more so if current policies are likely to stay. However, if emission standards are initially laxer, $\overline{\Omega} = \overline{\Omega}_b$, their relaxation by the same amount z, increases the profits of the dirty firms more than those of the clean firms, and this induces more firms to keep the current dirty technology. Indeed, what drives the firms' technological decision is the comparison between the fixed cost of adoption and the difference in the profits associated with the two technologies.

Let us now consider the effect of a change in emission standards on industry profitability. Total expected profits $E[\Pi]$ are given by

$$E[\Pi^T] = \gamma^T E[\pi_c] + (1 - \gamma^T) E[\pi_d] - \frac{1}{\overline{\Gamma}_i - \underline{\Gamma}_i} \int_{\underline{\Gamma}_i}^{\Gamma^T} \Gamma_i d\Gamma_i, \tag{19}$$

where the last term denotes the cost of adopting the clean technology (for the firms that adopt it). We can now prove that

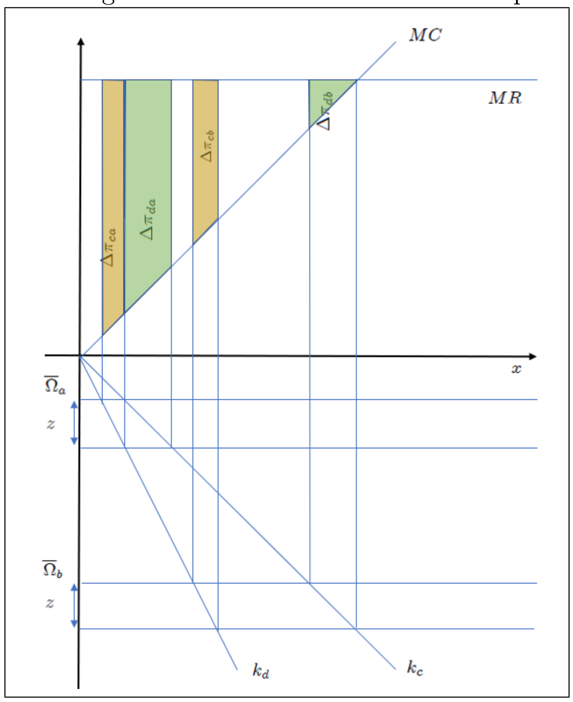
Proposition 2 *If the probability that the current government remains in power in period 1 is small enough, $\mu < \frac{z}{(2k_d - \overline{\Omega})}$, then a relaxation of the emission limit decreases the profitability of the industry; the opposite is true if $\mu > \frac{z}{(2k_c - \overline{\Omega})}$.*

[6] Indeed, we have that $\frac{\partial E[\Pi_c^T]}{\partial z} = \frac{\mu(2k_c - \overline{\Omega}) - z}{2k_c^2}$ and $\frac{\partial E[\Pi_d^T]}{\partial c_0} = \frac{\mu(2k_d - \overline{\Omega}) - z}{2k_d^2}$, $\frac{\partial E[\Pi_c^T]}{\partial z} > \frac{\partial E[\Pi_d^T]}{\partial z} \Longleftrightarrow z < \widetilde{z}$.

[7] To get a better understanding of the different forces at play, we considered a more general model, *à la* Perino and Requate (2012) where profit functions are concave, and firms choose among a continuum of technologies whose cost of adoption is increasing and convex in how green they are. In such a model, the effect of an increase in an emission quota depends upon the third derivative of the profit function. In the case of a quadratic profit function, a small increase in the emission quota leads to an increase in the adoption of green technologies, while a larger increase has the opposite effect (as in our model). Instead, with constant returns to scale, firms always adopt greener technologies when quotas are relaxed. We thank Quy-Toan Do for pointing this out.

[8] It is immediate to verify that $\frac{\partial \Gamma^{BT}}{\partial z \partial \mu} > 0 \Longleftrightarrow \overline{\Omega} < \widehat{\Omega}$.

Figure 1: Change in environmental standards and profitability



Proof: In Appendix.

Proposition 2 suggests that changes in emission standards that are designed to increase firms' profitability may end up having the opposite effect if the probability that they are reversed in the future is high, and technology cannot quickly adapt to the new regulations. The reason is that, in order to undo the damages that current policies are going to inflict on the environment, firms may end up facing draconian emission cuts in the future and this may negatively affect their (expected) profitability; this despite the fact that (expected) emissions also increase.

Finally, it may be worth remarking that the conditions set in Proposition 2 are sufficient conditions for an increase and a decrease in profitability, as they require all firms to gain or lose from the relaxation in the emission standards. This greatly simplifies the analysis as it allows us to ignore the effects of technological changes (induced by the change in policies) on the industry's profitability. We will discuss this in the robustness section below.

4 The California Effect

The question we discuss in this section is whether a subset of firms may find it in their self-interest to abide by emission standards that are stricter than those imposed by the government. We also discuss whether such a strategy is more likely to profit those firms that adopt (or are prone to adopt) the clean or the dirty technology.

The fact that firms may want stricter standards (if they anticipate that the current ones may be reversed) follows directly from Proposition 2. Indeed, when all firms are made worse off by the changes in the emission standards, they are necessarily better off if they can reverse them. Hence, the grand coalition of firms would necessarily find it in its self-interest to abide by stricter emission standards. The problem is that such a coalition is not stable: any (infinitesimal) firm will be better off by deviating from the stricter standards and free riding on the grand "green" coalition. This means that self-imposed standards may not work, and stricter standards may need to be enforced by subnational authorities, such as states. And if a state is large enough, it may find it in the interest of its firms to issue tougher emission standards even if other states do not follow.

But let us proceed by steps. First, we want to find out what is the smallest subset of firms ν, $\nu \in [0,1]$, that would find it optimal to abide by stricter emission standards, if such standards were externally enforced. If a subset ν of firms decides to abide by a tougher standard $\omega_T - \varepsilon$ and join the "green coalition," we would have that

$$\widetilde{\omega}^{AT} = \overline{\Omega} - \nu(\omega^T - \varepsilon) - (1-\nu)\omega^T. \tag{20}$$

Now, the total expected variable profits of a firm of type j belonging to the "green coalition" are given by

$$E[\pi_j^t] = (1+\mu)\pi_j^{\varepsilon}(\frac{\omega^T - \varepsilon}{k_j}) + \mu\pi_j^{\varepsilon}(\frac{\widetilde{\omega}^{AT}}{k_j}), \tag{21}$$

with

$$\pi_j^{\varepsilon}(\frac{\omega^T - \varepsilon}{k_j}) = \frac{(4k_j - \overline{\Omega} + 2\varepsilon - z)(\overline{\Omega} - 2\varepsilon + z)}{8k_j^2}, \tag{22}$$

$$\pi_j^{\varepsilon}(\frac{\widetilde{\omega}^{AT}}{k_j}) = \frac{(4k_j - \overline{\Omega} - 2\nu\varepsilon + z)(\overline{\Omega} + 2\nu\varepsilon - z)}{8k_j^2}. \tag{23}$$

We can then prove

Proposition 3 *If the probability that the current government remains in power in period 1 is small enough, $\mu < \frac{z}{2k_j - \overline{\Omega}}$, there exists a $\nu^{\Psi} < 1$, such that any coalition of firms of type j and of size $\nu > \nu^{\Psi}$ would gain from a stricter emission cap. ν^{Ψ} is smaller for the firms adopting a clean technology.*

Proof: In Appendix.

According to Proposition 3, if current lax standards are likely to be reversed in the future, then a subset of firms may prefer to abide by stricter emission standards today and tomorrow to be able to better "smooth" emissions (and production) over time. The problem, as we already mentioned, is that such a coalition is not stable. However, states may impose tougher standards (even if this is currently disputed in the U.S.). Do they have an interest in doing so? If states are small, they will face a free-rider problem similar to the one faced by individual firms. However, if a state is big enough, then it can unilaterally decide to impose stricter standards, and this may be in its firms' interest even if other states do not follow.

Notice that, in Proposition 3, we only considered coalitions of homogeneous firms, that is, of firms that have adopted either a clean or a dirty technology. The analysis can easily be extended to the case of mixed coalitions. In this case, the larger is the share of firms adopting the clean technology, the smaller is the coalition of firms that find it in their self-interest to abide by stricter emission standards. This, in turn, implies that the larger a state is, and the larger is its share of clean firms, the more likely it is that such a state is willing to impose stricter environmental standards. This is what we christen as the California effect.

5 Robustness

5.1 Large Changes in Regulation

In the previous analysis, we focused our attention on small changes in regulation assuming that $z < 2k_c - \overline{\Omega}$. In this section, we relax such an assumption and allow for any regulatory change that is compatible with assumption (A.3). First, it is important to notice that if the new emission cap is such that $\overline{\Omega} + z > 2k_d$, then it is non-binding and we can ignore it. Hence, in what follows, without loss of generality, we restrict our attention to the case in which $2k_d - \overline{\Omega} > z > 2k_c - \overline{\Omega}$.

When z belongs to such an interval, the emission limit is binding in period 0 only for the firms that operate with the dirty technology. This implies that $\widehat{x}_c^{*T} = 1$, $\widehat{x}_d^{*T} = \frac{\overline{\Omega}+z}{2k_d}$ and hence that $\widehat{\pi}_c^{*T} = \frac{1}{2}$, $\widehat{\pi}_d = \frac{(4k_d - \overline{\Omega} - z)(\overline{\Omega}+z)}{8k_d^2}$. In addition, we have that $\widehat{e} = \widehat{\gamma}k_c + (1-\widehat{\gamma})\frac{\overline{\Omega}+z}{2}$, so that, in period 1, if a new government is voted into office, it will set a limit $\widehat{\omega}^{AT} = \overline{\Omega} - \widehat{e}$. Thus, $\widehat{\Gamma}^T$ is the Γ_i that satisfies both

$$\Gamma_i = E[\widehat{\pi}_c^{*T}(\widehat{\omega}^{AT})] - E[\widehat{\pi}_d^{*T}(\widehat{\omega}^{AT})], \tag{24}$$

$$\widehat{\omega}^{AT} = \overline{\Omega} - \widehat{e}(\widehat{\gamma}), \tag{25}$$

where $\widehat{\gamma} = \frac{\widehat{\Gamma}^T - \underline{\Gamma}_i}{\overline{\Gamma}_i - \underline{\Gamma}_i}$.

While we are able to solve explicitly for the share of firms that adopt the clean technology and thus for the industry profits associated with different changes in emission standards, the expressions are quite convoluted. We thus present our results with the help of numerical simulation. They are summarized in the figures below, where we plot $\widehat{\gamma}$ and $E[\Pi]$ as a function of z, in the interval $[0, \overline{\Omega}]$, for different values of the probability that new emission standards would last, μ. In Figure 2, we set $\overline{\Omega} < \widehat{\Omega}$, and in Figure[9] 3, $\overline{\Omega} > \widehat{\Omega}$.

In the case of stringent emission caps, Figure 2, the relation between the number of firms that adopt the clean technology and the emission limits is hump shaped. The higher is the probability μ that policies are not reversed, the higher is the fraction of firms that adopt the clean technology. The effect of the relaxation of the emission standards on industry profitability also depends upon the probability that the new standards are going to be repealed. The higher the latter is (low value of μ), the more likely it is that laxer emission standards negatively affect industry's profitability.

Let us now move to the situation, depicted in Figure 3, where the original emission targets were less stringent. Also in this case, higher emission caps increase expected profits if they are likely to be permanent, and they reduce them if the probability that they are reversed is high. The number of firms switching to clean technology decreases the laxer the new standards are. Finally, we find that, for low values of z, the higher the likelihood of a policy reversal, the higher is the number of firms adopting the clean technology. The opposite happens for high values of z.

6 Conclusions

In this paper, we have attempted to explain two, somewhat surprising, developments following President Trump's decision to withdraw the United States from the Paris accord on climate change. First, private firms have continued to invest in clean technologies. Second, some state governments have decided to impose stricter environmental standards in the wake of weaker standards at the federal level. Using a simple model, we showed that profit-maximizing firms could increase the use of clean technologies because the increased output that these technologies permit raises profits by more than what the dirty technologies allow. This effect is stronger if firms believe that the change in the standards is permanent. However, we also showed that, if the relaxed emissions standards are likely to be reversed, industries will face a decline in expected profits—unless firms are able to form a coalition to adhere to stricter environmental standards. Since such a coalition is unstable, one possibility is for state governments, especially those of large states, to impose the standards.

While these explanations stem from a simple model, they provide important insights not just about the mechanisms through which environmental policy affects firms' and industries' decisions, but also in how we should interpret these developments following the U.S.'s withdrawal from the Paris accord. As the model shows, the increased use of clean technologies could be accompanied by an increase, rather than a decrease, in overall emissions. Hence, we should not be complacent about the fact that private firms are investing

[9] As per the parameter values, we set $k_d = 2$, $k_c = 1$, $\overline{\Gamma_i} = 2$, $\underline{\Gamma_i} = 0$. In Figure 2 we chose $\overline{\Omega} = .75$, while in Figure 3, we have that $\overline{\Omega} = 1.5$.

Figure 2: Stringent Initial Emission Targets

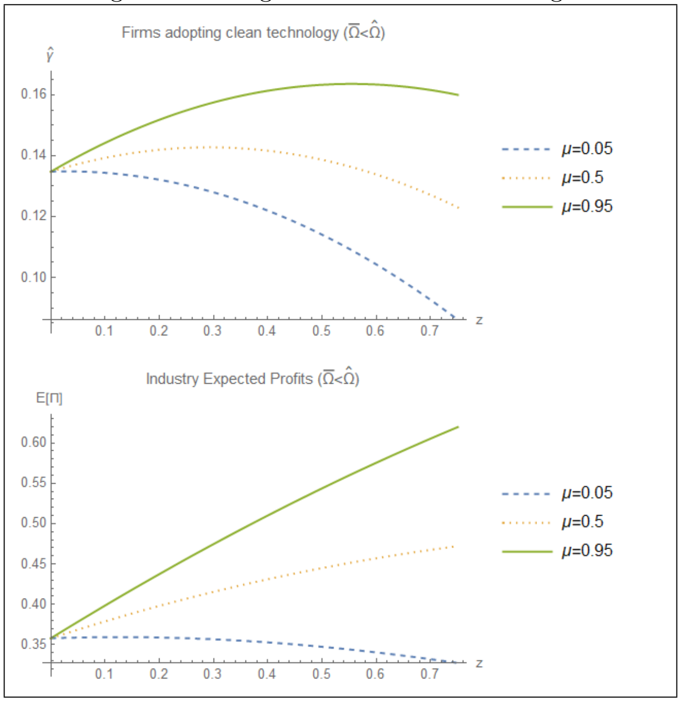
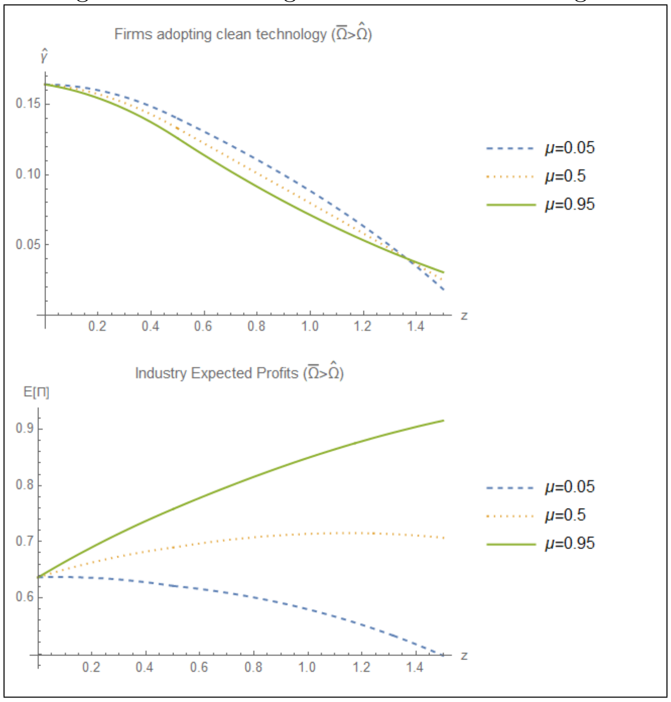


Figure 3: Less Stringent Initial Emission Targets



more in clean technologies. Similarly, if the stricter environmental standards at the state level are the result of lobbying by firms whose expected profits would otherwise be lower, then we should be leery about the underlying reason for the lower expected profits—the possibility that the relaxed environmental standards may be reversed. If this possibility is reduced, then the mechanism could work in the opposite direction and states may adopt laxer environmental standards.[10]

In sum, notwithstanding some encouraging developments about which we now have a better understanding, President Trump's decision to leave the 192-nation coalition on climate change may still undermine progress towards mitigating global warming.

[10] Of course, this is would not be the case if firms acted in a socially responsible way, see, for instance, Campbell, (2007).

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7 Appendix

Proof of Proposition 1

From (18) we have that $\frac{\partial \gamma^T}{\partial z} = \frac{1}{\overline{\Gamma}_i - \underline{\Gamma}_i} \frac{\partial \Gamma^T}{\partial z}$. Hence, differentiating (17), we have that

$$\frac{\partial \Gamma^{BT}}{\partial z} = \frac{(k_d - k_c)(2k_c k_d \mu - (k_d + k_c)\mu\overline{\Omega} - (k_d + k_c)z)}{2k_c^2 k_d^2(\overline{\Gamma}_i - \underline{\Gamma}_i)}, \tag{26}$$

from which it follows that

$$\frac{\partial \Gamma^{BT}}{\partial z} > 0 \Longleftrightarrow \overline{\Omega} < \frac{2k_c k_d}{k_c + k_d} - \frac{z}{\mu}. \tag{27}$$

Hence, if $\overline{\Omega} < \frac{2k_c k_d}{k_c + k_d} \equiv \widehat{\Omega}$, there exists a non-empty interval $[0, \widetilde{z})$, with $\widetilde{z} \equiv \mu(\widehat{\Omega} - \overline{\Omega})$ such that, if $z \in [0, \widetilde{z})$, $\frac{\partial \Gamma^{BT}}{\partial z} > 0$. The fact that $\frac{\partial \widetilde{z}}{\partial \mu} > 0$ completes the proof.■

Proof of Proposition 2

Notice that a sufficient condition for $\frac{\partial E[\Pi^T]}{\partial z} \lesseqgtr 0$ is that $\frac{\partial E[\pi_j^T]}{\partial z} \lesseqgtr 0$ for $j = c, d$. Indeed, if the relaxation of the emission limits increases the profitability of all firms for given technologies, then, a fortiori, it increases the industry profitability when firms can optimally choose technology. Moreover, if the relaxation of the emission limits decreases the profitability of both the firms that adopt the clean and those that adopt dirty technology, it is trivial to show that allowing firms to switch technology cannot completely reverse the effect. Differentiating (14) with respect to z, we have that

$$\frac{\partial E[\pi_j^T]}{\partial z} = \frac{(2k_j - \overline{\Omega})\mu - z}{2k_j^2}.$$

Hence, a sufficient condition for $\frac{\partial E[\pi_d^T]}{\partial z} < 0$ is that $(2k_d - \overline{\Omega})\mu - z < 0 \Longleftrightarrow \mu < \frac{z}{(2k_d - \overline{\Omega})} \equiv \widetilde{\mu}_1$. Instead, a sufficient condition for $\frac{\partial E[\pi_j^T]}{\partial z} > 0$, is that $(2k_c - \overline{\Omega})\mu - z > 0 \Longleftrightarrow \mu > \frac{z}{(2k_c - \overline{\Omega})} \equiv \widetilde{\mu}_2$, with $0 < \widetilde{\mu}_1 < \widetilde{\mu}_2 < 1$, because of (A.2).■

Proof of Proposition 3

A sufficient condition for the existence of a coalition of firms of type j that is willing to abide by stricter regulatory standard is that

$$\underset{\varepsilon \to 0}{Lim} \frac{\partial \pi_j^\varepsilon}{\partial \varepsilon} > 0.$$

Substituting (22) and (23) into (21), we have that

$$\begin{aligned} E[\pi_j^\varepsilon] \quad = \quad & \frac{1}{4k_j^2}(2(1 + \mu - (1-\mu)\nu)\overline{\Omega}\varepsilon - 2(1 + m + (1-\mu)\nu^2)\varepsilon^2 - \overline{\Omega}^2 \\ & -2\mu\overline{\Omega}z + 2(1 + \mu + \nu(1-\mu))\varepsilon z - z^2 + 4k_j(\overline{\Omega} - (1 + \mu - (1-\mu)\nu)\varepsilon + \mu z). \end{aligned} \tag{28}$$

Differentiating (28) with respect to ε, we have that

$$\frac{\partial \pi_j^\varepsilon}{\partial \varepsilon} = \frac{-2k_j(1 + \mu - (1-\mu)\nu) + T - 2\varepsilon + z + \nu(-\overline{\Omega} - 2\nu\varepsilon + z) + \mu((1+\nu)T - 2\varepsilon(1-\nu^2) + z(1-\nu)}{2k_j^2}, \tag{29}$$

so that

$$\underset{\varepsilon \to 0}{Limit} \frac{\partial \pi_j^\varepsilon}{\partial \varepsilon} = \frac{(2k_j - \overline{\Omega})((1-\mu)\nu - (1+\mu)) + (\nu(1-\mu) + (1+\mu))z}{2k_j^2} \equiv \Psi. \tag{30}$$

Furthermore, we have that

$$\Psi > 0 \Longleftrightarrow \nu > \frac{(1+\mu)(2k_j^2 - \overline{\Omega} - z)}{(1-\mu)(2k_j^2 - \overline{\Omega} + z)} \equiv \nu^{\Psi}, \tag{31}$$

and

$$\nu^{\Psi} < 1 \Longleftrightarrow \mu < \frac{z}{2k_j - \overline{\Omega}} \equiv \mu^{\Psi}.$$

This, together with the fact that $\frac{\partial \mu^{\Psi}}{\partial k_j} < 0$, completes the proof.■