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Abstract

[1]This paper provides a rationale for developing countries to announce future credible commitments to reduce GHG emissions even if these are not to materialize in the short run, and for domestic reasons only. A simple framework is presented in which it is shown that it may be costly for an economy to transition from high to low emissions; and that, if climate policy eventually will be enacted, then it may be better for countries to commit earlier and therefore eliminate the uncertainty for the private sector to invest appropriately in clean technologies. In particular, conditions are shown under which the private investor prefers a pre-announced climate policy, and how this policy affects investment decisions and the deployment of clean technologies.

JEL classifications: Q54, D81, H23

Keywords: Climate change, Mitigation, Developing countries

[1] We appreciate helpful comments by IDB/RES seminar participants and an anonymous reviewer.

1 Introduction

According to the latest projections by climate models, in order to achieve the targets of stabilizing concentrations of Greenhouse Gases (GHGs) by 2050 at levels that do not lead to potential catastrophic outcomes it is necessary that both developed and developing countries achieve a reduction in emissions.[2] Even if developed countries cut their emissions to zero, this would not stabilize global concentrations of GHGs. Thus it is very likely that developing countries will have to participate sooner rather than later in terms of reducing their emissions, or at least moderate the rate of growth of their emissions. Developing countries therefore face the challenge of deciding when to participate in climate change mitigation actions.

We argue that even if developing countries do not plan to impose any restrictions on GHGs emissions in the short run, they could benefit from today announcing when they would be planning to commit to real reductions. The idea relies on the fact that countries will eventually have to reduce emissions (or limit their growth), and given that many infrastructure investments have a long life-span, eliminating the uncertainty of when the policies will come into effect will eliminate wasteful infrastructure spending (i.e., on old, "dirty" technologies).

To this end we present a simple framework in which a private investor chooses between dirty and clean technologies under uncertainty regarding future climate policy. We find conditions under which the investor will choose each type. We then compare with the case of announcing the future climate policy. We show conditions under which the investor would choose the latter regime. We also show how the timing of the announcement and other characteristics of the investor affects the choice of technology. One key finding is that announcing future climate policy will induce technological change faster than the announced date, reducing investment in dirty technologies.

This paper departs from the traditional analysis in several ways. First, our focus of analysis is the firm. We claim that under plausible assumptions, even a profit-maximizing risk-neutral investor would prefer enacting climate policy sooner than later. Our second departure is that, since we focus on developing countries, we are not interested in the development and deployment of new technologies, as do most of the papers reviewed below. We assume that developing countries are just adopters of technology, and therefore the timing of policy would not affect the development of new technology. Our third main difference is that in our analysis we focus on the transition path to a new equilibrium and not on the equilibrium per se. That is, we look at effects on the transition period towards a climate policy that we "know" will be adopted in the future. Therefore our focus is not on the steady state but rather on the path to the new steady state from the private investor's point of view.

The rest of the paper is organized as follows. The next section summarizes the existing liter-

[2]See, for example, Edmonds et al. (2007) and Calvin et al. (2009) for two examples.

ature of the topic. Section 3 presents our simple framework, while Sections 4 and 5 discuss our main results. Section 6 discusses several extensions, and Section 7 concludes.

2 Literature Review

This paper belongs to the literature on delayed implementation of policies as well as climate policy. When to enact climate policy has been a topic of considerable debate, and the literature on the timing of climate policy has thus received many new contributions in the past few years. Several authors have argued that delaying climate policy adoption would be beneficial since there would be extra time to reduce uncertainty and verify whether the climate is in fact changing.[3] There would also be enough time to develop low-carbon technologies if the effects of climate change are as bad as some models predict. In the case of developing countries this would appear to be a dominating strategy as well. As Chisari and Galiani (2010) show, the optimal path for developing countries is probably to grow now and "clean up" later. The only reason for developing countries to adopt climate policy would be in lieu of some sort of international sanctions (such as carbon border tax adjustments) or given certain financial aid to adopt cleaner technologies.

Thus Goulder and Mattai (2000) find a lower time profile of optimal carbon taxes with induced technological change (ITC). When knowledge is gained through R&D investments, the presence of ITC justifies shifting some abatement from the present to the future. However, when knowledge is accumulated via learning-by-doing the impact on the timing of abatement is analytically ambiguous. In addition, Webster (2000) shows that, given the interaction between periods, a delay in policy might not be useful even if uncertainty is reduced due to the long-term effects of carbon emissions. Requate (2005) looks at the issue of timing and commitment and, comparing different second-best instruments, finds that committing to a menu of taxes dominates the other types. Golombek et al. (2010) look at the time consistency issue and find that subsidizing R&D technologies today would not create a time inconsistency problem with respect to future climate policy.

Finally, Gerlagh et al. (2009) look at the same issue but find that carbon taxes should be, if anything, initially higher to promote the development of new technologies.[4] Jaccard and Rivers (2007) examine delaying climate policy in the presence of heterogeneous capital stocks. They find

[3] However Weitzman (2009) argues that if as a consequence of climate change the world faces so called catastrophic climate change and if the statistical process behind this event exhibits “fat-tails,” then, even if these probabilities are low, the expected value of the negative outcome should overtake any possible cost of avoidance and thus delay of implementation would be welfare reducing. Nordhaus (2009), however, has challenged this analysis mainly on the grounds that Weitzman (2009) assumes that the cost of climate catastrophe is infinity, while under very high but bounded estimates, the expected costs of catastrophe are significantly reduced.

[4] It must be noted, though, that climate-specific R&D subsidies are still preferred as a means to promote development and deployment of new (low-carbon) technologies.

that, given that significant economic activity uses long-lived capital stocks, then optimal climate policy for these sectors would involve early targeting of CO2 emissions. Shalizi and Lecocq (2009) consider the effect of inertia in long-lived capital stocks and show that carbon markets on their own are unlikely to be able to generate enough emission reductions to stabilize emissions, justifying the fund-based approach that has overtaken carbon markets in developing countries. Strand et al. (2011) find that if the capital stock can be retrofitted to reduce emissions (for example, using carbon capture and sequestration in coal-fired power plants) then the optimal policy may be to delay full implementation of climate policy until the future.

Williams III (2010), in the paper perhaps closest to this one, looks at the time profile of environmental policy. The paper show that the optimal (deterministic) phase-in of environmental (climate) policy for quantity (e.g., cap and trade) and price (e.g., carbon taxes) mechanisms is different. For quantity mechanisms the optimal mechanism is a gradual phase-in, while for a price mechanism to optimal policy is to set the initial price at the optimal level once and for all.

This paper also belongs to the literature on the "green paradox" as proposed by Sinn (2008). The green paradox basically implies that increasing the current price of oil (e.g., using carbon taxes) and committing to a high tax in the future can decrease the current international price as oil producers will want to extract as much oil as possible in the present, thus increasing emissions today. Overall Sinn (2008) argues, the net effect of the carbon tax on GHG concentrations is negligible since we have only traded future emissions for current emissions In that vein the paper closest to our is by Smulders et al. (2010). Their paper can generate a "green paradox" by pre-announcing climate policy instead of relying on exhaustible resources as in the Sinn (2008) paper. However their results rely on a key assumption on the investment versus operating costs of both technologies. In our case we can also generate the "green paradox." As can be observed, however, it is far from being the most likely outcome of the model.

One critique to the approach explored in this paper is that of time (in)consistency. As Kydland and Prescott (1977) showed, governments may have incentives to abandon policies that were previously committed to. However, in practice once a law has been passed it is not generally easy to reverse. Although policy reversals and changes exist, we do not observe countries reversing policies very often.[5] Moreover, since policy uncertainty can be costly in terms of economic growth and political support, governments would rather avoid it if possible. Finally, it is at least plausible that developing countries will tend to adopt climate policy due to international pressure, thereby reducing the possibilities of reversing the policy. In this context, pre-committing to a climate policy for the future may even benefit the country in terms of reduced international pressure, or higher access to markets for their products.

[5] Fernández and Rodrik (1991) and Coate and Morris (1999) present two different explanations on policy persistence or status quo bias.

There is also extensive evidence that many policies are carried out in gradual ways, with pre-announced commitments. For example,there are examples of unilateral policies establishing a timetable for tariff reduction that can last several years, and in the case of Free Trade Agreements they often last a decade or longer.[6] Two other examples, the Montreal Protocol on CFCs and the Kyoto Protocol, were both phased in over a long period of time (with, of course, substantially different success rates).

3 A Simple Model

Assume there is a private investor that every period chooses to invest in a project with two possible technologies. The first (dirty) technology has a period return of R_D if no climate policy is enacted and zero if climate policy is in place. The second (clean) technology has a period return of $R_C < R_D$ regardless of the existence of climate policy. We further assume that both technologies have the same investment horizon (lifetime) of T, such that it can be used for T periods and is then abandoned. The period discount factor is δ and assumed constant. It is useful to define the function $V(R, T, \delta)$ as the present discounted value at period 0 of an annuity of R during T periods with a discount factor of δ and the first payment in period 1.[7] That is:

$$V(R, T, \delta) = \sum_{t=1}^{T} R\delta^t = R\frac{\delta - \delta^{T+1}}{1-\delta}$$

The expected value of the clean technology project is given by:

$$V_C = V(R_C, T, \delta)$$

while the expected value of the dirty technology project will depend on the probability of the country enacting climate policy. To keep the algebra simple, assume that in each period the probability status quo is equal to p, so the probability of the country deciding to enact climate policy is $1 - p$. Therefore this probability can be combined with the discount factor in a very simple way. Thus the expected value of a dirty investment project will be given by the expression:

$$V_D = V(R_D, T, \delta p)$$

[6]A few examples include Chile's unilateral tariff reduction that went from 11 percent to 6 percent over a five-year period. Free trade agreements Chile and the United States and Chile and the European Union both had 10-year reduction schedules, while Chile's agreement with MERCOSUR included a 17-year moratorium for some products.

[7]The assumption is that the investor chooses which project to undertake in period 0, but only starts receiving payoffs starting in period 1. This is consistent with the fact that normally long-lived capital projects are rarely completed in a short period of time.

From these two expressions we can find parameter values in order to compare the value of both dirty and clean technology projects, and see how this difference depends on each of the 4 parameters, R_C/R_D, p, δ and T.

Remark 1. *(i) Until climate policy is enacted the investor always chooses to invest in the same technology. (ii) Once the climate policy is enacted, the investor chooses always the clean technology.*

The second part is trivial since $V_C > 0 = V_D$ with climate policy. For the first part we observe that given p, δ, T, R_C and R_D constant, then if for a given period $V_C < V_D$, then the investor chooses the dirty technology, and unless the climate policy is enacted, then this will also be true in $t+1$. If the reverse is true, then the investor always chooses the clean technology. Thus, the investor always chooses the same technology until climate policy is in place.

Next we equalize the present discounted values of both technologies and reorganizing terms one can obtain:

$$\frac{R_C}{R_D} = p\frac{1-\delta}{1-\delta p}\frac{1-(\delta p)^T}{1-\delta^T}$$

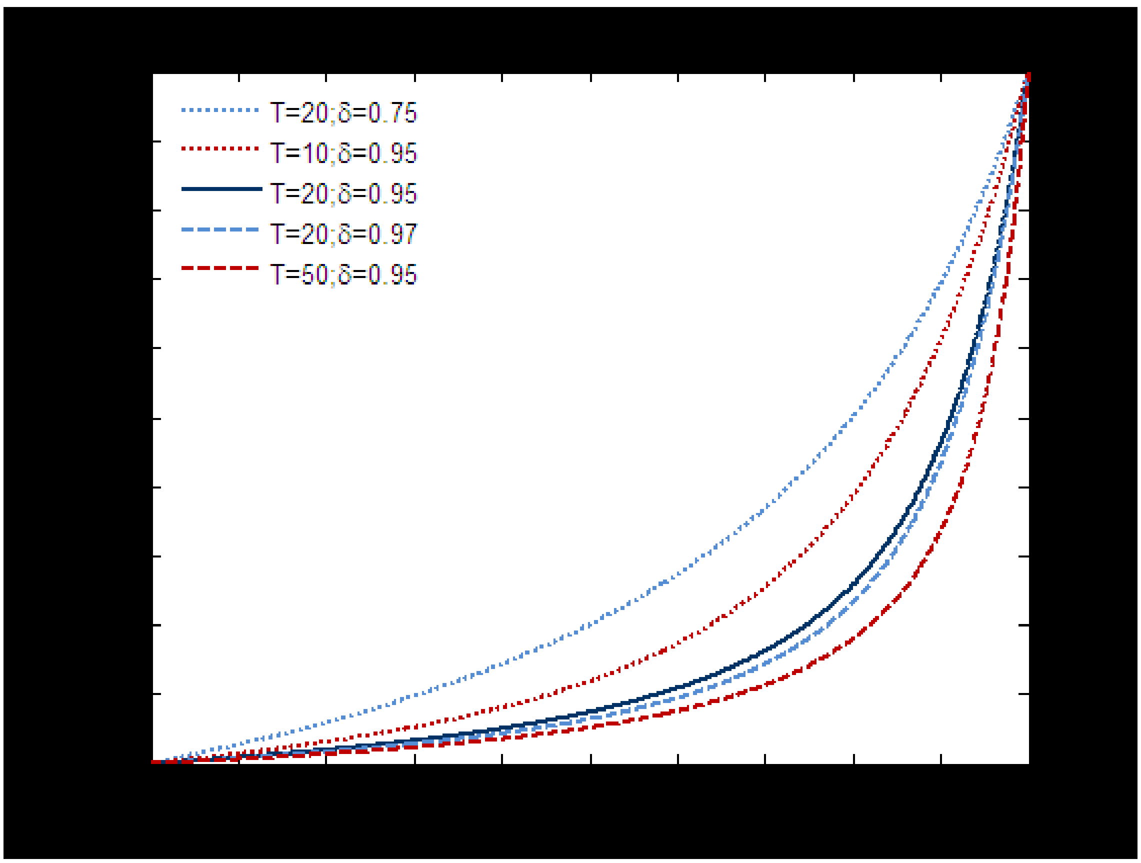
We can use this expression to do some comparative statics on each one of the four parameters mentioned before. First, the effect of the flow payoff of both technologies, R_C/R_D, and the probability of keeping the status quo, p, are straightforward in the choice between both technologies. The effect of the probability of the status quo is direct, seeing that the right hand side of the previous expression is increasing in p. The effect of the horizon is direct, too, as a longer horizon will increase the risk that some climate policy change would be implemented, so a higher T is more favorable to a clean technology. This can be seen in the last expression because the right-hand side is decreasing in T. Finally, a higher discount factor, that is a more patient investor, increases the relative value of the clean technologies over the dirty ones, because the future risk of a change is more important in the evaluation. Again, in the last expression the right-hand side is decreasing in δ, an effect that coincides with the intuition. The Appendix presents formal proofs of these statements.

Figure 1 presents this comparative static graphically. The figure shows the required ratio R_C/R_D makes the private investor indifferent between both technologies, for different combinations of the other parameters.

As can be observed, the curvature increases with the time span of the project and a higher discount factor. Both imply that clean technologies will be preferred the longer the project lasts and the lower the discounting.

Figure 1. Required Ratio R_C/R_D for Indifference

1



4 Eliminating the Uncertainty: Announcing Future Policy

Now assume that the government can credibly announce and pre-commit to enact climate policy in $T^* < T$ periods, which will be in effect the next period.[2] Of course, this does not change the expected value of the clean technology, but it does change the expected value of the dirty technology. The present value of the dirty technology with the new announcement is now given by:

$$V_{DA}(T^*) = V(R_D, T^*, \delta)$$

That is, the uncertainty is eliminated but the horizon of planning is changed too. Now one can compare this value with the value of the clean technology. One can see that $V_C = V_{DA}(T^*)$ if and only if:

$$\frac{R_C}{R_D} = \frac{1 - \delta^{T^*}}{1 - \delta^T}$$

Let us define T_C as the announcement term, T^*, that solves the last equation. And solving we find that:

Proposition 2. *There exists a* $0 < T_C < T$ *such that for all* $T^* > T_C$*, then* $V_{DA}(T^*) > V_C$.

Proof. By simple inspection we can see that $V_{DA}(0) < V_C$, while $V_{DA}(T) < V_C$. Thus by continuity there must exist T_C such that $V_{DA}(T_C) = V_C$. Given the monotonicity of the expression with respect to T^* the desired result holds.

What this proposition shows is that there exists a period T_C such that announcing the policy to be effective in T_C makes the investor indifferent between both technologies. Thus an investor that each period invests in one of these projects will have the following optimal strategy summarized in this corollary.

Corollary 3. *The profile of investment of an investor under a pre-announced climate policy will be to choose a dirty technology until the time left for the policy to be in effect is less than* T_C*. At that moment the investor will begin to invest only in clean technology.*

Proof. It is straightforward from the definition of T_C.

The result above shows that in a pre-announced world the use of a dirty technology will be limited to a certain date. This deadline will be periods before the policy change is implemented,

[2] We choose that climate policy is in effect the period after it is enacted, since it simplifies notation. Otherwise, expected values would entail a T-1 term.

and in this model the number of periods is T_C. So, if the authority wants the technological change to occur at a certain date, the announcement should be made for the policy to be effective in future date. This difference between the date when the policy is implemented and the date when the relevant change is produced is important and depends on the other parameters of the system. For example, as the discount factor increases then the gap between the change in the technology and the implementation of the change increases.

5 When Is It Profitable to Eliminate Uncertainty?

Now the question is what changes when an announcement is made. We assume the government is credible, so we do not focus on time inconsistent issues. First, the present discounted value of a dirty technology under announcement can be summarized as the following:

$$V_{DA}\left(T^*\right)=\begin{cases} R_D\frac{\delta-\delta^{T^*+1}}{1-\delta} & \text{if } T^*<T \\ \\ R_D\frac{\delta-\delta^{T+1}}{1-\delta} & \text{if } T^*\geq T \end{cases}$$

It is clear that $R_D\frac{\delta-\delta^{T+1}}{1-\delta}$ is greater than V_C and V_D. Let us define T_D as the solution of the following equation:

$$V_{DA}\left(T_D\right)=V_D$$

That is, the term that makes the investor indifferent between the investment in a dirty technology with an announcement and the investment under uncertainty in a dirty technology. Given $V_{DA}\left(T^*\right)$ is strictly increasing in the relevant range these equations have a unique solution. The next figure show this relations in the one relevant cases, that is, when $V_D>V_C$.

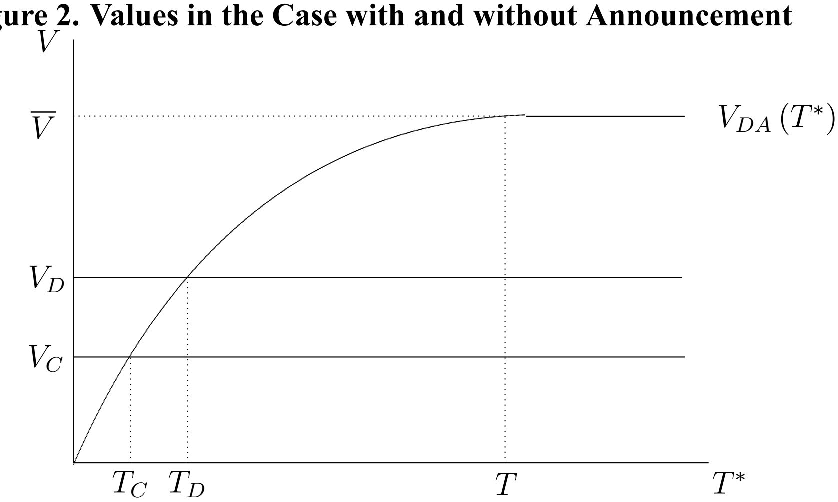
The relevant result of the paper is stated in the following proposition:

Proposition 4. *Suppose R_C/R_D, p, δ and T are such that $V_D>V_C$, then there exist a unique $T_D\left(R_D,p,\delta,T\right)$ such that for all $\hat{T}>T_D$ exist a unique $\tau\left(\hat{T}\right)$ that holds:*

i For all periods $t<\tau\left(\hat{T}\right)$ the private investor prefers to invest in a dirty technology

ii For all periods $t>\tau\left(\hat{T}\right)$ the private investor prefers to invest in a clean technology

Figure 2. Values in the Case with and without Announcement



In particular, at $t = 0$, the private investor in a dirty technology is better off with the announcement at $\hat{T}$ than without it.

Proof. The existence of a unique $T_D(R_D, p, \delta, T)$ is given by the definition of this variable. Moreover, if $V_D > V_C$ then $T_D > T_C$. Take any $\hat{T} > T_D$, then $\tau\left(\hat{T}\right)$ solves the following equation:

$$\tau\left(\hat{T}\right) + T_C = \hat{T}$$

In this case, for all $t < \tau\left(\hat{T}\right)$ it holds $V_C < V_{DA}\left(\hat{T} - t\right)$, so the investor prefers the dirty technology. Any period after the last inequality is reversed. The case $t = 0$ is just base in $\hat{T} > T_D$ and the fact that $V_{DA}\left(\hat{T} - t\right)$ is strictly increasing.

The previous proposition states that the reduction of uncertainty could make the dirty technology more profitable in the short run, but for sure will make the clean technology more profitable in the future. This result does not include the effect of the reduction of the variance in the expected revenues, since the model assumes risk-neutral investors. Including this effect should increase the benefits from the pre-commitment climate policy, raising investors' expected return for both clean and dirty technologies even further.

There are at least three considerations with respect to this last result.

The first is that one can show that the expected time of the occurrence of the change, $E[T]$, is greater than the minimum time required to make an announcement profitable for the private sector that uses dirty technology today, T_D. That means that if one announces at $t = 0$ that the change will be effective at the expected time, the private sector that uses dirty technology today will be better off, and the technological change will start sooner, in fact, T_C periods in advance. The only sector that is negatively affected in this scenario is owners of dirty technology, that would want to continue to invest in this type of technology after the policy enactment.

The second consideration is related to the restriction of this improvement. A pre-announcement requires that the commitment is credible. If the country can commit to this change in the future, then there is a space for a gain given the reduction in uncertainty. On the other hand, if the country cannot commit, or if its commitment is not credible, then the only possibility is the uncertainty being resolved when the climate policy is enacted, and not in advance. That is, the gains of the pre-announcement are based on the credibility of the country's regulators.

Finally, it is worth noting that the government has a range of possible timings to choose a policy that both increases the expected return to the private sector and reduces emissions, i.e., is good for the environment. However, this relies on the assumption of $V_D > V_C$ initially. If this is not the case we get the following corollary.

Corollary 5. *Green Paradox: Suppose R_C/R_D, p, δ and T are such that $V_D < V_C$, then:*

- *if the announcement term $T^* < T_C$ the private investor will be unaffected by the elimination of the uncertainty and will continue preferring the clean technology.*
- *if the announcement term $T^* > T_C$ then the point [i.] of this proposition holds and a green paradox emerges.*

Proof. Straightforward from $T^* < T_C$ implies $V_{DA}(T^*) < V_C$.

Thus, if the change in technology has already begun, due to perception of either a high discount factor or low probability of status quo, then we generate the green paradox, which will shift investment back into the dirty sector at least for a while.

Now we can undertake some comparative statics on $\tau\left(\hat{T}\right)$, that is, the period when the clean technologies will be the optimal private choice. Given the definition of this variable one finds the solution solving the following system of equations:

$$\tau\left(\hat{T}\right) = \hat{T} - T_C$$
$$\frac{R_C}{R_D} = \frac{1-\delta^{T_C}}{1-\delta^{T}}$$

where the second equation comes from the definition of T_C. So, given a fixed $\hat{T}$, $\tau\left(\hat{T}\right)$ is decreasing in R_C/R_D, T, and δ. The implication of this result is that if different investors have different discount factors, even if the announcement is common for both, then one will begin investing in the clean technology before the other. As an extension, this implies that if investors from different countries face different discount factors (for example, due to different risk premiums) then countries with lower discount factors (higher risk premium) will delay the deployment of clean technologies compared to countries with higher discount factors (i.e., lower risk premiums).

6 Discussion and Extensions

We can summarize the results obtained here by highlighting the following considerations. As mentioned above, the announcement or pre-commitment has a positive environmental outcome (i.e., a shift from investing in dirty to clean technologies earlier than without the announcement) if the investor was initially facing a high probability of status quo or low discount factors, or the relative return to the clean technology was very low. In addition, we also observe that if the project's lifetime (T) is very short then this works against clean technologies.

From these elements one can hypothesize about how these different variables might affect the adoption of clean technologies. In principle we should expect poor countries and high-risk countries to have fewer incentives to shift to clean technologies. The former is due to the fact that the probability of status quo is likely decreasing in income as richer countries will probably face more international pressure to curb emissions. Countries that have low emissions or low emission intensity would also probably face less international pressure.[3] The latter is due to the fact that, as was mentioned earlier, high-risk countries will probably face low discount factors and therefore investors that do not care much about the future. We should also expect different adoption of technologies in different sectors. Projects that are short-lived have fewer incentives to shift towards cleaner technologies, and of course costly projects will also face smaller incentives. This could, for example, explain why consumers may not care about the electricity consumption of a mobile phone and to some extent why they do not buy hybrid cars, but may be interested in weatherproofing their homes, buying an efficient heat pump, or switching from electric heating towards gas. It could also explain why countries have tended to adopt wind farms rather than solar power plants.

On the other hand, one could extend the model to allow for a large range of additions. If we knew for certain that the clean technology will become more (relatively) profitable over time, then the space for improvements would be reduced and the timing of the shift in technology would move towards an earlier date. However, if the returns to the clean technology are uncertain (in the stochastic sense), then waiting might be a better alternative for the firm.[4] In addition to this, we could introduce the possibility of a retrofit to the dirty technology at a given cost.[5] This, as is also

[3] Thus China would face increasing pressure on the emissions side, but somewhat reduced pressure since the country is still very poor.

[4] Goulder and Mattai (2000) and Strand et. al. (2011) stress this point when they find that higher uncertainty might induce the firm to do less rather than more today.

[5] For example, carbon capture and storage technology that could remove (and store) carbon emissions from a coal-fired

shown by Strand et. al. (2011) would "help" the dirty technology by allowing it to operate at a given cost and therefore have a positive stream of income even under the climate policy.

An additional point that may be raised, as mentioned in the literature review, is that of credibility. However, our model to some extent captures both extremes of the credibility issue. If the government is not credible, then the investor would disregard the announcement and behave as if the announcement did not occur. On the other hand, if the government is credible, then our result follows. Partial credibility should generate some intermediate result given the monotonicity of our results, but this may depend on the structure of beliefs of different agents.

Finally, it is worthwhile to consider a model where the restriction of the investment per period is relaxed. This model is more general, and it is being examined in ongoing research project. The basic structure and preliminary result of this model are presented below.

6.1 An Alternative Approach

In this subsection we will relax the restriction of investing in one plant every period. In order to do that we solve the dynamic problem of a monopolist in a market where the demand is growing at a deterministic rate. The monopolist can choose the amount to invest at each point in time, and the investment has a depreciation rate. We use a discrete time model. The idea is to keep the model as simple as possible. The market inverse demand for the final product at time t is given by:

$$P\left(t\right)=A\left(t\right)-BQ\left(t\right)$$

The parameter $A\left(t\right)$ reflects the increase in the market size (i.e., growth in the economy). Let us start with the case where there is only one available technology, represented by a constant marginal cost c and an investment unitary cost κ. It is easy to see that if there is no uncertainty, and no excess capacity in the first period, then the capacity will never be higher than the quantity that the monopolist sells in each period. Thus one can concentrate on the case where the capacity is equal to the quantity sold in every period. The monopolist problem can be represented by the following Bellman equation:

$$\begin{aligned}&V\left(K,A\right)=\max_{Q,I}\left\{P\left(Q,A\right)Q-cQ-\kappa I+\beta V\left(K+I-\delta K,A+\Delta\right)\right\}\\&\text{s.t. } Q=K\end{aligned}$$

where β is the discount factor, κ the investment unitary cost, δ the depreciation rate, and Δ the

power plant or other facility.

growth of A from one period to the next.[6] The policy function of the previous Bellman equation determines the optimal path of investment.

$$K(t) = \underbrace{\frac{A(t) - C}{2B}}_{Static\ optimal} - \underbrace{\frac{\kappa}{2B}\left(\frac{1}{\beta} - (1 - \delta)\right)}_{Dynamic\ effect}$$

That is, the optimal dynamic quantity differs from the static one. Later one needs to add a new technology and evaluate when it is optimal for the private investor to choose between one or the other. As a preliminary result one can state the following:

If the parameters of cost, discount factor, and probability of status quo are in the range where the dirty technology is preferred to the clean one before the change, then the solution can be summarized in three steps:

- - Before the change happens, the private investor will invest in dirty technology at a rate that will incorporate the probability of status quo.
  - After the policy implementation, the private investor will invest in clean technology as fast as possible, but under certain conditions the dirty technology will continue be the marginal in the market.
  - If the tax on dirty technology is high enough, then the clean technology will be the only one on the market after the adjustment. If the tax is lower, then the dirty technology will disappear from the market given depreciation.

In the case of a pre-announcement, the preliminary results show that the adjustment period will be anticipated, as before. The length and costs of these stages are part of ongoing research.

As a summary, relaxing the constraint on investment per period, one has a similar flavor of the result with or without announcement, but there are new variables that need to be considered. These new features are a stage of adjustment and the level of the tax.

7 Conclusions and Further Work

We have presented a very simple model in which a private investor in a developing country that will have to face some type of climate policy restriction in the future may prefer to know in advance when that restriction will be in place. The main idea behind this is that, given that investments last

[6]This growth rate could depend on the time or the value of A, but in this simple case this is not relevant and one can omit this dependence.

for long periods, if investors are going to face a large negative shock it is optimal to know in advance when this would occur, and therefore phase out old technologies in a relatively cost-effective way. Thus the main result of this paper is that some private costs are avoided by implementing the announced policy.

The model so far has assumed a market in which the return to each investment is exogenous, which may not be completely realistic for some sectors/countries. In particular, the power sector has some of the characteristics of long-lived capital, but it is perhaps organized as oligopolies or regulated monopolies in which investment decisions affect the return on investment. Taking this into account may well change optimal behavior and thus policy choice. A second extension is to consider that the probability of climate policy is not constant but rather increasing over time since the pressure on developing countries to adopt climate policy is rather unlikely to diminish and very likely to increase.

A testable prediction that would be interesting to explore is to see if investors in long-lived capital projects are more willing to demand some type of climate policy than investors in shorter-term projects.

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Appendix

7.1 Net Present Value for Dirty and Clean Technologies:

We start from the following equation.

$$\frac{R_C}{R_D} = p\frac{1-\delta}{1-\delta p}\frac{1-(\delta p)^T}{1-\delta^T}$$

The effect of R_C/R_D is direct. The effect of p is straightforward if one rewrites the right-hand side as

$$p\frac{1-\delta}{1-\delta p}\frac{1-(\delta p)^T}{1-\delta^T} = \frac{\delta p-(\delta p)^T}{1-(\delta p)^T}\frac{1-\delta^T}{\delta-\delta^T}$$

The first term is increasing in p and the second term is independent of p. The effect of T can be seen taking the difference of the right-hand side evaluated in one period and the period after.

$$\begin{gathered}
p\tfrac{1-\delta}{1-\delta p}\tfrac{1-(\delta p)^T}{1-\delta^T} - p\tfrac{1-\delta}{1-\delta p}\tfrac{1-(\delta p)^{T+1}}{1-\delta^{T+1}} = \\
p\tfrac{1-\delta}{1-\delta p}\tfrac{1-(\delta p)}{1-\delta}\left[\tfrac{\sum_{t=1}^{T-1}(\delta p)^t}{\sum_{t=1}^{T-1}\delta^t} - \tfrac{\sum_{t=1}^{T}(\delta p)^t}{\sum_{t=1}^{T}\delta^t}\right] = \\
p\tfrac{1-\delta}{1-\delta p}\tfrac{1-(\delta p)}{1-\delta}\tfrac{1}{\sum_{t=1}^{T-1}\delta^t\sum_{t=1}^{T}\delta^t}\left[\left(\sum_{t=1}^{T-1}(\delta p)^t\right)\delta^T - \left(\sum_{t=1}^{T-1}\delta^t\right)(\delta p)^T\right] = \\
p\tfrac{1-\delta}{1-\delta p}\tfrac{1-(\delta p)}{1-\delta}\tfrac{1}{\sum_{t=1}^{T-1}\delta^t\sum_{t=1}^{T}\delta^t}(\delta p)^T\left[\left(p^{-T}+\ldots+\delta^{T-1}p^{-1}\right) - \left(1+\ldots+\delta^{T-1}\right)\right]
\end{gathered}$$

Given $p < 1$, the last expression is strictly greater than 0. So a longer T is more favorable to the clean technology.