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Waiting for Clarity: How a Price on Carbon Can Inspire Investment

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Key Findings

- Uncertainty about the strength and durability of climate policy, which is exacerbated by the lack of carbon pricing, is likely hindering investment at a time when enabling economic recovery and fostering future growth are especially pressing.
- Economic theory and empirical evidence suggest the introduction of carbon pricing does not harm and may amplify economic recovery during recovery from economic recession, supporting the notion that resolving climate policy uncertainty can be a stimulus for economic growth.
- The role that policy uncertainty plays in impacting investment is generally ignored in studies of the cost of climate policy. Most studies implicitly consider policy scenarios as alternative cases each of which is implemented with "certainty," and they therefore do not recognize or value the economic benefits and costs of policy properly.
- Climate science justifies stringent and urgent climate policy action, but such action is not on the agenda in many jurisdictions. Inaction, on the other hand, may impart economic costs by perpetuating policy uncertainty that stifles investment, which is important to economic recovery after COVID.
- Durable carbon prices—even modest ones—can have outsized influence on long-run investment and emissions by shaping expectations about future policies that drive greater investment.

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1. Introduction

The COVID-19 pandemic and associated business lockdowns have created a major economic slowdown that at its low point in April of 2020, included a loss of 22 million jobs and a monthly GDP loss of roughly 20 percent from pre-pandemic levels. While the situation improved somewhat in the subsequent months, the economy is far from recovered a year into the pandemic and most economists agree that a full and timely recovery will require government stimulus. At the same time, evidence of the severe and long-term economic costs of a changing climate have become increasingly visible. As the US works to end the pandemic and restore the economy to its former health, calls to address climate change through government action at the federal and state levels are getting louder, and President Biden has declared a commitment to reducing US emissions to **net zero by 2050**.

Both overcoming the recession and achieving deep decarbonization will require substantial private-sector investment. Most policy discussion of ways to spur those investments, particularly for purposes of economic recovery, have focused on direct federal spending as the primary mechanism to stimulate growth. Moreover, there is a general understanding that for the many specific economic sectors and communities most affected by the pandemic, a return to normalcy will result in different economic circumstances than existed previously. Careful targeting of recovery investment dollars to sectors and communities that have been hardest hit and that are likely to face the greatest continued disruption is **seen** by many observers as a strategy to promote decarbonization while providing economic stimulus and is **an important part** of the Biden administration's commitment to "build back better."

Synergies between efforts to spur investment and to address climate change are not limited to the targeting of federal spending. Resolving climate policy uncertainty can also play a stimulative role. Generally, regulatory uncertainty increases borrowing costs for firms (Henderson and Salant 1978). Recent literature (Fried et al. 2021) suggests that investor uncertainty about the direction of climate policy can reduce investment by reducing the expected returns to investment. Uncertainty of potential climate policy leads to emissions reductions by making the capital stock slightly smaller and cleaner, but it does so at twice the cost to the economy that would be achieved by a carbon price that is calibrated to achieve the same emissions outcome. Lemoine (2017) finds that expectations over future climate policy can alter investments in fossil fuels technologies and affect the current price of fossil fuels. Another study (Jha et al. 2020) finds that uncertainty around proposed local air quality regulations increased interest rates faced by state and local governments, and those interest rates declined when those regulations were finalized, and the policies became clear.

Yet the role that policy uncertainty plays in impacting investment is generally ignored in studies of the cost of climate policy. Greater certainty about future policy paths can come from policies to price carbon and from policies that take other forms, such as clean energy standards or emission rate standards, the adoption of which both provide clarity on current policy and can provide signals of the direction of future policies. Arguably, the most transparent policy signal that provides confidence about the direction of policy in general is a carbon price, implemented through either a carbon fee or a cap-and-invest program, which can spur private capital investment by providing clarity on the expected future profitability of different types of investments.

In this report, we describe how eliminating policy uncertainty by setting climate policy can help to spur economic investment, suggesting a potential synergy between climate policy and economic recovery. We use simple models to illustrate the economic idea of option value in shaping investment incentives in the presence of policy uncertainty. We then examine the empirical evidence about the effect of carbon pricing on economic activity at the country level and extend that evidence by looking specifically at the effects of introducing carbon pricing into economies that are recovering from economic recession. We find preliminary evidence that the introduction of carbon pricing does not harm and may amplify economic recovery in those countries, supporting the notion that resolving climate policy uncertainty can be a stimulus for economic growth.

2. Review of Evidence of Carbon Pricing's Effect on Economic Activity

The prevalent understanding about the effects of carbon pricing on economic activity is informed by two types of evidence that yield somewhat conflicting results. One source of evidence is the literature that makes use of computable general equilibrium (CGE) simulation models to analyze how carbon prices (and other policies) affect the whole economy. A general equilibrium model analyzes the economy as a whole, rather than on a sector-by-sector basis, employing stylized but comprehensive mathematical representations of markets and technologies and relationships between them. Most CGE simulation models find small negative effects on economic activity from a carbon price, although those estimates do not account for environmental benefits. For example, the Goulder-Hafstead E3 model estimates that a $40 per metric ton carbon price would reduce GDP by about 0.1 to 0.3 percent in the long run, where the outcome depends on how the carbon revenue is used (Goulder et al. 2019). These models typically do not incorporate policy uncertainty and thus, they compare scenarios where a policy is known for certain to a situation where the policy does not exist and there is certainty about that. Neither scenario is particularly realistic. Thus, these models are not able to account for the role of policy uncertainty or the economic value of eliminating policy uncertainty.

The other source of evidence on the effect of carbon pricing on economic activity comes from empirical or econometric studies (Metcalf and Stock 2020, Metcalf 2019, Bernard et al. 2018, Yamazaki 2017, Abdullah and Morley 2014). In general, these studies tend to find little evidence of negative economic effects and a few find some evidence of small positive effects on growth. Reasons for the disparity between the simulation modeling and empirical literatures are not well understood; however, one possible explanation for why the empirical results are more optimistic than the simulation results could be that the empirical studies implicitly capture the positive impacts on economic growth of signaling policy certainty to investors. This observation suggests that the elimination of uncertainty that comes with new policies could explain the different findings from these two approaches.

3. Model of Option Value and the Value of Waiting

3.1. Intuition Behind Option Value

The concept of "option value" represents the **value** of the **option** to **wait** for better information before having to make a decision, such as an investment decision (Dixit and Pindyck 1994). In the climate policy context, government policy will likely change the value of investments in energy infrastructure. Consequently, uncertainty about government commitment to climate policy may encourage investors to wait for more clarity before making investment decisions (Fuss et al. 2008). It is well known that option value creates an incentive to wait for that better information to arrive before sinking resources into an investment.

To build intuition for this concept, suppose you are faced with a decision about whether to invest in a carbon-free (green) resource or an emitting (fossil) resource, suppose you are presented with a pair of standard six-sided dice—one green and one fossil—that represent the possible payoffs from each investment ($1 through $6, corresponding to each side of the die), and you are offered the following choices:

a. Choose one of the two dice (either green or fossil), roll the die, and then receive a dollar amount based on the value on the die that you chose,

   or

b. Roll the pair, look at results, then choose which die's outcome (green or fossil) you would like to base your payment on.

Which option would you choose, a or b? Clearly the answer is b—you would rather wait until the uncertainty is resolved to make your choice. This simple example illustrates the **value** of preserving the **option** to make your choice. In fact, the expected payment of option a is $3.50, whereas the expected payment of option b is about $4.50. The extra $1 expected from selecting option b is known as the "option value."

3.2. Basic Model Setup

To ground the idea more firmly in the context of energy investments, we build a simple model of investment uncertainty in the style of Dixit and Pindyck (1994). An investor is considering investing in a "green" renewable asset, such as a 280-megawatt (MW) wind farm, or alternatively a carbon-emitting fossil asset, such as a natural gas combined cycle power plant that is expected to produce the same amount of electricity.

The profit of each investment, in net present value terms, is the discounted flow of revenues (which depends on the electricity price and generation, and potentially on a carbon price) minus each asset's respective capital and operating costs (CAPEX and

OPEX). We base the parameters for each asset's cost and operating profile (CAPEX, OPEX, capacity factor, and emissions intensity) on recent estimates from the 2020 Annual Technology Baseline (ATB) produced by the **National Renewable Energy Laboratory** (NREL). These parameters are shown in Table 1. The systems are sized to have the same expected generation of approximately 1 million megawatt-hour (MWh) per year each and receive the same market price for electricity.

For the fossil asset, the operating costs include both the direct costs of operating the plant as well as a carbon price, should one be implemented. We model the implementation of a carbon price—implemented as either a tax or an emissions cap as uncertain today, but should the price be implemented, the level of the price is known ex ante (see discussion in Box 1).

Box 1. Price Uncertainty under Carbon Taxes and Caps

We model a carbon tax level as known (say, $60/ton of CO2) but investors are uncertain about whether this tax will be implemented. This policy could reflect a carbon tax of $60/ton or a cap-and-trade program that yields an allowance price of the same. More generally, if the carbon policy were a cap-and-trade program, there would remain uncertainty about the level of the market price, but the policy would enable investors to observe the government's commitment to an emissions target and to manage their own investments in face of carbon price variability as they do with variability in the price of other production factors such as natural gas. Increasingly, carbon markets are introducing market stability measures such as price floors that mitigate the variability in market prices. Thus, we abstract from uncertainty about prices within a carbon market, instead focusing on the expected price of compliance with a known policy commitment, and alternative policy outcomes.

While no carbon price is in place in year 1 ("today"), there is some chance in the near future (year 2) that the government imposes one. For example, for the purposes of the model we assume a 25% chance that a $60/ton carbon price is implemented in year 2.[1] To build intuition, we start with a simple two-period model; once it is revealed in year 2 whether the price is enacted, the price stays fixed at that level ($0/ton or $60/ton) forever. (We extend this assumption in the infinite horizon model in a subsequent section.) We also allow some fraction of the carbon price to be passed onto the consumer by increasing the price of electricity received by the investor.

1 While 25% may seem high, the qualitative lessons of the model hold for a wide range of alternative assumed probabilities.

A decision to invest in a plant initiates construction resulting in the plant becoming operative one year later. In year 1 (today), before it is known whether the carbon price will be implemented in year 2, the investor considers three options:

1. invest in the green asset (e.g., the wind farm),
2. invest in the fossil asset (e.g., the gas plant), or
3. wait until year 2 to decide.

Under our model parameters, the fossil asset would be more profitable absent a carbon price, but the green asset would be more profitable with the price in place. With the looming prospect of making the wrong choice, the investor has a clear and intuitively obvious incentive to delay the decision until next year, when the policy outcome is known. On the other hand, this incentive is partially offset by the time value of money; by waiting to make the investment, the investor loses out on a year's worth of potential profits. The net value of waiting (that is, relative to the payoff from investing today) is known as "option value."

Table 1. Model Parameters

Common Parameters	
Carbon Price (τ)	\$60/ton CO_2
Probability of Carbon Price (φ)	25%
Energy Price (p), before Passthrough	\$43/MWh
Passthrough Rate (α)	50%
Discount Rate (r)	10%

Unit Characteristics	**Green (Onshore Wind)**	**Fossil (Natural Gas)**
Capacity	280 MW	208 MW
Capacity Factor	40.9%	55%
Generation (q)	1.003 million MWh/year	1.003 million MWh/year
Emissions Rate	0	0.34 tons CO_2/MWh
Carbon Price per Unit of Energy	\$0/MWh	\$20.38/MWh
CAPEX	\$1.60 million/MW	\$1.09 million/MW
OPEX	\$0/MWh	\$19.80/MWh
Capital Cost (k_G, k_F)	\$449 million	\$227 million
Annual Operating Cost (c_G, c_F)	\$0	\$19.80 million

3.3. Numerical Results for Two-Period Model

Using the parameter values from Table 1, we calculate the net present value (NPV) of profits under the three alternative investment options (choosing green, fossil, or waiting) for a two-period model in Table 2. The three columns show NPV profits under three cases: one where the $60/ton carbon price is implemented, one where no carbon price is implemented, and finally the uncertain case where there is a 25% chance that the $60/ton carbon price will be implemented in year 2. Recall that the plant comes online with a one-year lag. In each case, the most profitable strategy is written in **bold green** font.

With the carbon price implemented for sure, the green asset is the clear choice, producing $84 million in NPV profits. Without the carbon price, the fossil asset is the clear choice, generating $6.8 million in NPV profits. When the carbon price remains uncertain, investing in the green asset is better than investing in the fossil asset, but the best approach is to wait.

The net present values are calculated as follows. In the uncertain case, investing in the green asset would produce $7.6 million in *expected* profit. which is the probability-weighted average of receiving $84 million in profits with a 25% chance and a *loss* of $18 million with a 75% chance ($7.6 = $84 × 25% - $18 × 75%).[2] Rather than investing immediately, it is better to wait until year 2 to make the choice, and then investing in the green asset should the carbon price be implemented and investing in the fossil asset otherwise. This approach generates $84 million with a 25% chance, and $6.8 million with a 75% chance. Because the investor must wait one year to construct the plant and to receive this payoff, the present value is discounted at the discount rate of 10%, resulting in a NPV profit of $24 million ($24 = ($84 × 25% + $6.8 × 75%)/1.1). This outcome easily dominates the profit of immediately investing in either the green or fossil asset. In this example the value of waiting to make an investment when the policy outcome is uncertain—the "option value"—is $16.2 million, reflecting the difference in the expected profits from waiting ($24 million) and the expected profits that would be earned by investing immediately (here, the $7.6 million expected profit from the green investment). By contrast, we observe that if the carbon price were implemented right away it would spur immediate investment in green energy. In summary, through the mechanism of investment decision making under uncertainty, implementing a carbon tax now could stimulate economic growth.

2 Figures may not equate due to rounding.

Table 2. NPV Profits in millions of dollars, under alternative options and conditions (Maximum profit strategy in each column is shown in green), two-period model

	Profit *with tax* for sure	Profit *with no tax* for sure	Expected profit with *uncertain tax*
Invest in green asset in year 1	**$84.31**	–$17.93	$7.63
Invest in fossil asset in year 1	–$95.42	**$6.82**	–$18.74
Wait until year 2	$84.31/1.1 = $76.65	$6.82/1.1 = $6.20	($\frac{1}{4}$×$84.31 + $\frac{3}{4}$×$6.82) / 1.1 = **$23.81**

3.4. Model Extension: Infinite Horizon

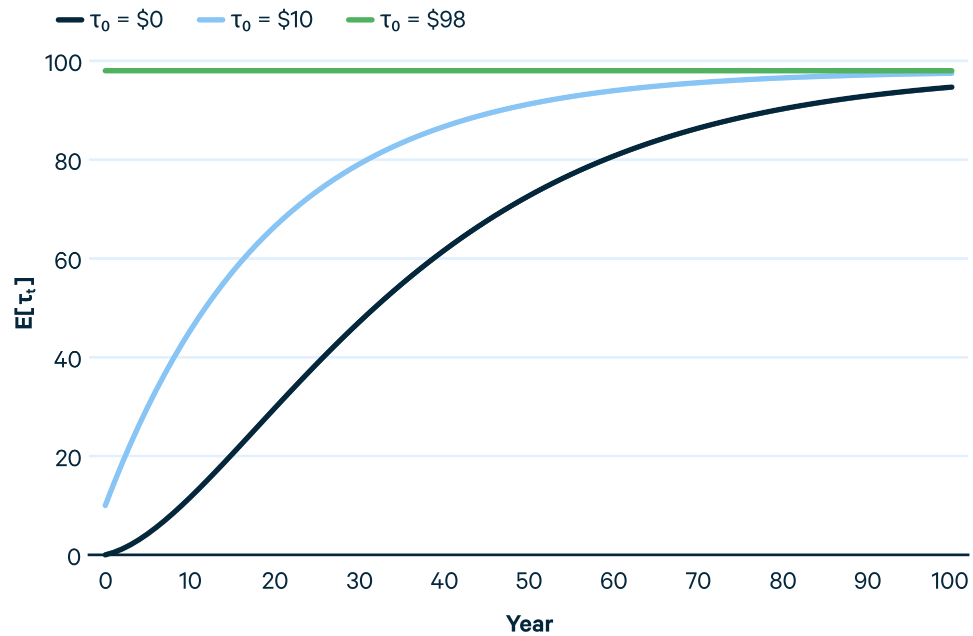
The two-period model above assumes a very simplified structure of carbon policy uncertainty: either the carbon price is implemented in year 2, or it is not, and the policy never changes after that. However, carbon policies, once implemented, are typically adjusted over time. Historically, carbon prices tend to become more stringent over time and are only rarely repealed (as seen in Australia, New Jersey, and Ontario, although in the latter two cases the price was soon reinstated). Further, the two-period model does not capture the effect that even modest carbon prices can have on expectations about future policy, creating another mechanism by which even small prices can accelerate investment.

Specifically, we extend the model to allow the carbon policy to vary every year forever, while also allowing the investor to wait indefinitely to make their decision. To be concrete, we consider three different possible carbon prices: $0/ton (i.e., no price), a modest price of $10/ton, and a high price of $98/ton. The $98/ton is approximately the value that Kaufman et al. (2020) estimate will achieve net zero emissions. We must make some assumptions about the probability of the policies changing each year. We assume that policies are highly persistent (or "sticky"), tend to rise over time, and that a high price is inevitable given enough time. Specifically, we assume that if the price is $0 in a given year, there is a 95% chance it will remain at $0 in the next year, and a 5% chance that a modest $10 price is implemented. We make an analogous assumption about the $10 price: if there is a $10 price in place in a given year, there is a 95% chance that it remains at $10 in the next year, and a 5% chance that it is increased to $98. Once the $98 price is implemented, it is assumed to be in place forever.

While we focus on this structure of carbon prices and their chance of changing over time, the results are qualitatively similar for other realistic assumptions. Specifically, the optimal strategies (waiting to invest when there is no price on carbon and investing in the green asset when there is a modest or high price) are unchanged if we change the $98/ton value to any level above $21/ton, or if we reduce the probability of price increases from 5% each year to 2%.

The expected future path of carbon prices, starting from a year when it takes on each of the three values, is illustrated by the three lines in Figure 1. The black and blue lines show expected future prices starting from a year with no price (black) and a $10 price (blue). Note how even a modest price of $10 in the initial period leads to a large jump in expected future prices compared to no price, simply because it dramatically raises the chance a $98 price will be implemented soon. This observation suggests that even a modest price can lead to large changes in the relative expected profitability of carbon-free and carbon-intensive investments, thereby encouraging investment.

Figure 1. Expected Carbon Prices Over Time in the Infinite Horizon Model



The results of the infinite horizon model are given in Table 3 and Table 4. Table 3 shows the NPV profits that would be calculated by a **myopic** investor, who does not consider expected future changes carbon prices, but rather assumes that the current situation will persist forever. The first column is the same as the "no price" case in Table 2, column 2; when there is assumed to be no carbon price forever, and the fossil asset is preferred. The myopic investor will then invest in fossil assets. With a modest price in place, the investor finds neither investment profitable and makes no investment. Only in the high price scenario does the myopic investor choose to build a green asset.

By contrast, in the "no price" case, a (more realistic) forward-looking investor will delay investment indefinitely until the modest price is implemented. While the green asset is expected to be NPV positive without the price (based largely on the expectation that the price will eventually be implemented), the green asset is much more profitable with even a small price and it makes sense to wait for that price to be enacted.

Interestingly, the modest $10 price has its effect almost entirely through its role as a signal that a $98/ton price is more likely to be adopted in the future. Note that the myopic profits in Table 3 show that the green asset is slightly NPV negative at a price that is fixed at $10 forever. The only reason it is strongly NPV positive in Table 4 (forward-looking) but not in Table 3 (myopic) is because of the effect the modest price has on expected future carbon prices and their effect on future electricity prices (see Figure 1). Hence, the modest price plays two roles. It serves to importantly change the payoff to investments in the near term, causing swings of approximately $17 million in payoffs for each of the green and fossil investments from a myopic viewpoint. It also has a primary role and potentially more important role in a forward-looking investment environment as a policy signal that indicates to investors the direction of future policy, thereby encouraging investment in the near term. While the modest price directly swings the payoffs by about $17 million in the myopic case without accounting for future expectations about future policy changes (Table 3, compare columns 1 and 2), the total effect is a much larger $47 million when accounting for those expectations (Table 4, compare columns 1 and 2). In other words, the true effect of the modest carbon price is nearly three times larger ($47 versus $17 million) when one accounts for how a policy sends a signal to investors about future expectations.

Table 3. *Myopic* NPV Profits in millions of dollars, under alternative options and conditions (Maximum profit strategy in each column is shown in green), infinite horizon model

	Currently No Carbon Price (τ = $0)	**Currently Modest Carbon Price** (τ = $10/ton)	**Currently High Carbon Price** (τ = $98/ton)
Invest in green asset	–$17.93	–$0.90	**$149**
Invest in fossil asset	**$6.82**	–$10	–$160

Table 4. *Forward-Looking* NPV Profits in millions of dollars, under alternative options and conditions (Maximum profit strategy in each column is shown in green), infinite horizon model

	Currently No Carbon Price (τ = $0)	**Currently Modest Carbon Price** (τ = $10/ton)	**Currently High Carbon Price** (τ = $98/ton)
Invest in green asset	$6.64	**$54.09**	**$149**
Invest in fossil asset	–$17.75	–$65.20	–$160
Wait a year	**$18.03**	$53.49	$136

3.5. Durable Carbon Policies are Key to Addressing Climate Goals

Whether a carbon policy is viewed as durable—meaning that the carbon policy is politically sustainable as well as designed to effectively achieve the necessary level of climate ambition—is a critical consideration for investment decisions. A durable policy does not necessarily imply a fixed and unchanging carbon price pathway over time. One of the virtues of a carbon market is that it communicates an environmental goal to economic actors. Over time, prices may fluctuate in the carbon market, providing valuable information about investment opportunities and least cost options for emissions reductions. Price variations do not undermine investment decisions directly. Firms have experience with variations in prices for inputs such as natural gas and they have tools such as hedging contracts that enable them to move forward with investments in the face of uncertainty about those prices. Indeed, the ability of a policy to adapt to new information may be essential to its durability, and changes in allowance prices are one way that new information is brought into decisions about how to comply with the policy and may help the policy to endure.

However, uncertainty about policy is different. Investment decisionmaking is strongly dependent on underlying carbon policy. Changes in policy cannot be easily hedged or planned for, and this risk introduces fundamental uncertainty that can disrupt investment decisions. Hence, we are interested primarily in the durability of policy. *Throughout this discussion we refer to changes in the carbon price only as a proxy for potential changes in the policy, recognizing implicitly that prices in a market inherently move over time.*

Previously, we noted in the infinite horizon model that adoption of a modest carbon price might signal a change in the likelihood of a more stringent and durable price in the future. Both components are necessary; the modest price must signal to investors that a higher price is likely to come, and that the policy underlying that higher price is durable, meaning unlikely to be quickly reversed. In practice, there are a few ways this might actually occur.

A durable carbon pricing policy can trigger sufficient investments to spawn new industries with associated interest groups that become advocates for stringent carbon policies as Pahle et al. (2017) argue occurred in California and Germany. A modest carbon price might provide political and economic viability leading to policy diffusion across jurisdictions, as identified by Dolphin and Pollit (2021). The design of a carbon pricing mechanism might evolve through incremental alignment and learning between jurisdictions, as Burtraw et al. (2013) observe across the EU, the Regional Greenhouse Gas Initiative (RGGI), and California. Some policy designs are mutually reinforcing and might embody inherent natural tightening. For example, carbon markets that permit banking of allowances create inherently valuable assets that form a constituency of allowance holders that is vested in the program's durability and may profit from increased stringency, as has been observed in RGGI and the EU. Carbon asset value might be directed to entities in a way that grows support for carbon pricing, as argued by the advocates of directing carbon revenues as dividends to households (Barnes 2001). Those revenues also can themselves be stimulative or spur further emissions reductions.

While the discussion in this report thus far reflects an expectation of a one-way direction of increasing stringency of carbon policy and higher prices, there have been some historical instances of carbon pricing policies being repealed—that is, not durable. The option value model can be used to think about the importance of the durability of a price, not just its level. A policy's durability is inevitably connected to economic and political realities, and in particular the effects of potential policy repeals were carbon prices to become politically unsustainable either due to the price being set so high that is politically unsustainable or so low that stakeholders and investors expect additional policies will need to be implemented without any certainty on timing, price, or stringency. Moreover, lack of durability could be due to, for example, a failure to create a constituency for the policy, or a failure to incorporate community feedback and thereby deterring stakeholders who might otherwise be supportive.

To consider the implications of such a scenario, suppose the $98/ton price reflects a poorly designed policy with little constituency and is thus likely to be quickly cut or repealed. Specifically, suppose that when a $98/ton price is in place, it remains in place next year with only a 25% chance, is repealed with a 50% chance, or is cut to $10/ton with a 25% chance. This scenario could be thought of as the same policy as in the previous section, but where the policy yielding the $98/ton was crafted in a politically vulnerable way. The expected price paths in this case are displayed in Figure 2, showing that in the medium-term expected carbon prices are in fact higher when starting from a durable $10/ton price (that is likely to remain in place or be increased, see blue line) than when starting from a non-durable $98/ton price (which is likely to be repealed, see green line).

Accordingly, Table 5 shows that, perhaps counterintuitively, investment is now only optimal when the modest price is in place. This outcome occurs because of our assumption that a high price year is likely to be followed by a repeal. Instead, the investor prefers the relative stability of the modest price. This example demonstrates how a high but fragile carbon price could be worse than a low but durable one. This finding is true for even short run outcomes because investors make decisions today based on anticipated future carbon prices, not just current ones.

The example is not a commentary on the level of the carbon price directly, but rather it illustrates the value of policy durability. Durable carbon prices are ones that are designed to achieve broad support. For example, a high price may be designed to be durable by returning tax revenues to individuals through lump-sum dividends, or through other design choices that lock in strong support. In a similar vein, the lump-sum stimulus checks of $1,200 and $1,400 per person in 2020-2021 achieved broad, bipartisan **support**. Durability may also be enhanced by being viewed as sufficiently ambitious to address the necessary mitigation. More generally, the outcomes in each of these carbon price examples depend on the transition probabilities between different price levels that we construct artificially. Nonetheless, they illustrate that expectations about future policy outcomes influence short run investment decisions. Consequently, policy decisions in the short run can have out-sized influence on emissions in the long run by shaping expectations about future policies.

Figure 2. Expected Carbon Prices Over Time in the Infinite Horizon Model, with Non-Durable Policy

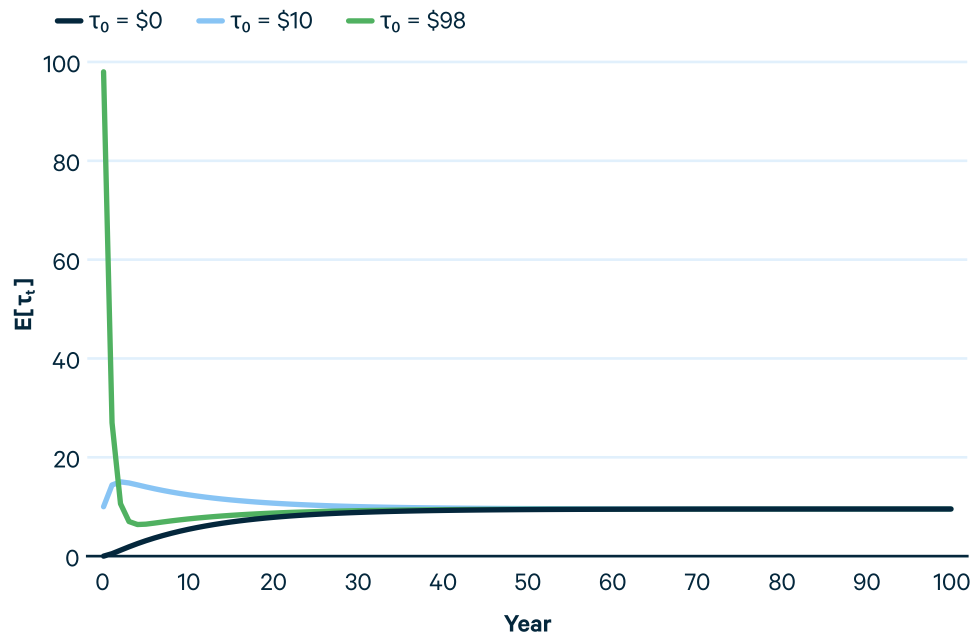


Table 5. *Forward-Looking* NPV Profits in millions of dollars, under alternative options and conditions (Maximum profit strategy in each column is shown in green), Infinite Horizon Model, with Non-Durable Policy

	Currently No Carbon Price (τ = \$0)	Currently Modest Carbon Price (τ = \$10/ton)	Currently High Carbon Price (τ = \$98/ton)
Invest in green asset	–\$10	**\$39**	–\$1.5
Invest in fossil asset	–\$1	–\$15	–\$10
Wait a year	**\$1.3**	\$3.4	**\$1.9**

4. Empirical Evidence

While the above model is loosely calibrated to costs representative of wind and gas-fired power generation, it is nonetheless largely theoretical. To add an empirical lens, we turn to the European experience with carbon taxes, many of which preceded the implementation of the EU emissions trading system, to explore whether the empirical evidence is consistent with the idea a carbon price can encourage investment. Figure 3 shows for the level and coverage of these taxes. This is particularly relevant in a time of economic slack, such as in the aftermath of the COVID-19 pandemic.

A recent study (Metcalf and Stock 2020) examined the growth rate of economic activity (GDP and employment) following the implementation of carbon taxes in many countries across Europe. We use the data from that study to conduct two simple analyses. First, we simply compare economic growth rates before and after each country adopted its carbon tax. Figure 4 shows these growth rates over time for each country. The blue lines depict annual GDP growth rates over time for each country, with the vertical dashed line indicating the year that the country introduced its carbon tax. The horizontal lines indicate pre-tax and post-tax average growth, alongside 95 percent confidence intervals. Simple pre/post comparisons show little evidence of negative effects. The only country that saw significant economic contraction after implementing its tax was Finland in the early 1990s, but that recession was caused by the Finnish banking crisis and as well as the collapse of the Soviet Union, both of which are unrelated to carbon pricing (**Honkapohja and Koskela 1999**). Thus, a simple look at GDP growth rates indicates no obvious negative effect of carbon pricing.

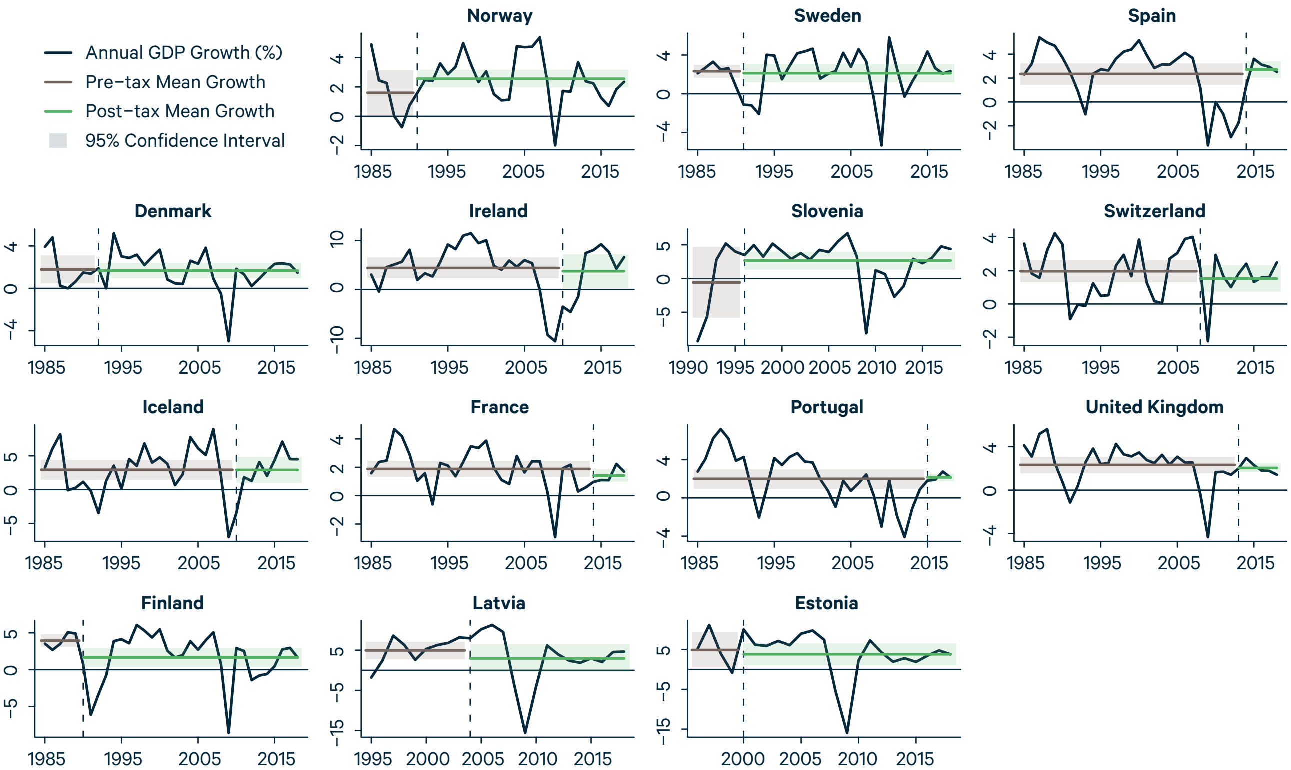
Further, several countries implemented carbon taxes during times of recession (Iceland, Ireland, Spain, and to a lesser extent Estonia), yet none saw a noticeable drag in the rate of their recoveries. Of course, a simple before-and-after comparison is not a rigorous analysis of all possible effects. For example, the effect of carbon taxes might be delayed, indicating a before/after comparison would be inadequate. The effect is also likely to vary with the size of the carbon tax, which a before/after comparison does not take into account. It could also be that countries with positive economic growth trends may be more likely to implement a carbon tax. Metcalf and Stock (2020) estimate an econometric model on this same data that takes all of these factors into account to isolate the effect of the carbon tax itself. They find no statistically significant effect of taxes, and in fact their central estimate is that carbon taxes produce a positive but economically negligible and statistically insignificant economic benefit. They also recognize that there could be heterogeneous effects; they consider whether countries that use the revenues from a carbon tax to reduce taxes, finding larger benefits in those countries, although again the estimate is statistically insignificant.

Because this paper is considering the potential for a carbon price to encourage investment at times of economic slack, we consider a different source of heterogeneity: economic conditions when the price is enacted. Specifically, we run the same econometric model as Metcalf and Stock (2020) but only including carbon taxes that were implemented in the year following a recession (that is, Iceland, Ireland, Spain, and Estonia, see Figure 4). The results of that analysis find no evidence that carbon prices reduce growth in either GDP or employment. The point estimates are generally reflective of economic benefits, although they are for the most part statistically insignificant. This suggests that carbon prices are consistent with and may accelerate economic growth, and that the benefits are—if anything—stronger in times of recession. While this result does not offer conclusive evidence that option value explains the benefits of carbon pricing, it is strongly consistent with the theory of option value.

Figure 3. Carbon Tax Levels and Coverage[3]

3 Carbon tax levels represent values in the year the tax was implemented. Emissions coverage reflect values in 2019 due to data limitations.

Figure 4. Annual GDP Growth (%) by Country, Before and After Implementing a Carbon Tax (in descending order by size of tax in implementation year)



5. Discussion

A great deal of debate in the economics and policy sciences surrounds the choice of climate policy and its stringency, and in particular the level of a price on carbon emissions (or generally, the stringency of the policy goal). The debate is often framed as a tradeoff between economic growth and reduced emissions. If climate change follows the pathway of many other environmental challenges, environmental degradation may eventually translate into effective policy measures. Unfortunately, unlike environmental challenges like air pollution, the effects of climate change are cumulative, compounding, and potentially irreversible. Hence, there is an urgency to act. However, the policy debate remains engulfed in concerns about perceived big tradeoffs—big costs and big consequences. By contrast, we find that these tradeoffs are often overstated, and climate policies do not inherently constrain economic growth.

Given the current lack of comprehensive climate policy in many jurisdictions, this paper points to the value of durable policies, even if modest to start, in shaping investments that enable more substantial emissions reductions driven by more stringent policies in the future. A durable policy, even with a modest carbon price, could stimulate climate-friendly investments and have short-run economic benefits. This can occur because even a modest carbon policy can signal long-term commitment of government and enable near-term accelerated investment in the economy in general, and in mitigation technology and infrastructure specifically. A carbon price today that is seen by industry and investors as durable can provide industry and investors' confidence that a carbon price at some level will continue into the future and may increase.

Although the example we develop is the introduction of a carbon price, commitments to various climate policy mixes may provide similar benefits by shaping expectations about the policy future and create onramps to enable carbon pricing (Meckling et al. 2017; Pahle et al. 2018). Stepping stones that enable increasingly stringent climate policy might address distributional goals, promote directed technological change, develop technical knowledge and legal institutions, and build political and economic constituencies. However, among these incremental policy measures, we believe the most transparent policy signal that provides confidence about the direction of policy in general is a carbon price. In the face of inaction otherwise, a durable carbon policy that includes a carbon price, even if initially modest, offers a win-win outcome with respect to economic growth and carbon mitigation. Most importantly, we show that a carbon price could do more than expected from expected value calculations, could accelerate investment in green technology, and could stimulate economic growth.

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Appendix

This appendix describes the models of investment behavior and option value in mathematical detail. The first section describes the two-period model, and the second section describes the extension to infinite an horizon.

A.1. Two Period Model

A.1.1. Conceptual Model

An investor can invest in either a green or fossil asset. It takes 1 year to build.

Both generate q units of output, leading to pq flow revenues in perpetuity, starting next year. We assume q is fixed/exogenous. Some share ρ of the tax is passed on to consumers, as discussed below. The key parameters are

- r…the discount rate
- k_G, k_F…capital costs, accrued in $t = 0$. $k_G > k_F$.
- c_F…variable O&M costs ($\$/q$). Assumed to be zero for the green asset, and $p > c_F$.
- τ…carbon tax ($\$/q$), enacted in period 1 with probability ϕ, equal to $\overline{\tau}$. The expected tax is $E[\tau] = \phi\overline{\tau}$.

A share of the tax, denoted α, is passed on to consumers, so that the price received by generators is given by $p + \alpha\tau$.

Given this, the profits earned by each option if the firm invests in period 0 are given by $\pi_{G,0}$ and $\pi_{F,0}$ for the green and fossil options respectively, are given by:

$$\pi_{G,0}(\tau) = -k_G + \sum_{t=1}^{\infty} \frac{(p + \alpha\tau)q}{(1+r)^t} = -k_G + \frac{(p + \alpha\tau)q}{r} > 0$$
$$\pi_{F,0}(\tau) = -k_F + \sum_{t=1}^{\infty} \frac{(p + \alpha\tau - c_F - \tau)q}{(1+r)^t} = -k_F + \frac{(p - c_F - \tau(1-\alpha))q}{r}$$

Both $\pi_{G,0}(\tau)$ and $\pi_{F,0}(\tau)$ are uncertain because the realized tax (and the amount passed through to consumers) is uncertain. If $\alpha = 0$ (no passthrough) then green profits are not uncertain, and if $\alpha = 1$ (full passthrough) then fossil profits are not uncertain.

Suppose that, if the firm knew for certain whether there was a tax, it makes sense to invest in green if there is a tax, but fossil if not:

$\pi_{G,0}(\overline{\tau}) > \pi_{F,0}(\overline{\tau})$ if the tax is enacted ($\tau = \overline{\tau}$)

but

$\pi_{G,0}(0) < \pi_{F,0}(0)$ if not ($\tau = 0$)

The condition that leads to this is

Assumption 1: $\frac{c_F q}{r} < k_G - k_F < \frac{(c_F+\bar{\tau})q}{r}$ …. i.e., the extra capital costs of the green asset are larger than the costs of operating without the tax but smaller than the costs of operating with a tax.
If we had to make an investment today, we would choose green if

$$E[\pi_{G,0}] > E[\pi_{F,0}],$$

or equivalently, $\frac{(c_F+\phi\bar{\tau})q}{r} > k_G - k_F$.

Note that the relative value of the two investments does not depend on the passthrough assumption (α). This is because the passthrough effect on the price increases the revenues of both investment options equally.

For expositional purposes, we will assume this condition holds—that is, in expectation, green power is preferred, and the investor would choose green if she had to decide today:

Assumption 2: $\frac{(c_F+\phi\bar{\tau})q}{r} > k_G - k_F$

Even still, choosing green is not necessarily the investor's best (profit-maximizing) strategy. In other words, even if green power is expected to be the cheaper option, an investor may not "greenlight" an investment until she is clear whether a carbon tax is in place. The idea is that an investor may not want to commit to NPV-positive green investments until she is sure that fossil investments won't be even better.

Table A.1. Expressions for Profits under alternative options and conditions

	Profit with tax for sure	Profit with no tax for sure	Expected profit with uncertain tax
Invest green at $t = 0$	$-k_G + \frac{(p+\alpha\bar{\tau})q}{r}$	$-k_G + \frac{pq}{r}$	$-k_G + \frac{(p+\alpha\phi\bar{\tau})q}{r}$
Invest fossil at $t = 0$	$-k_F + \frac{(p - c_F - \bar{\tau}(1-\alpha))q}{r}$	$-k_F + \frac{(p-c_F)q}{r}$	$-k_F + \frac{(p - c_F - \phi\bar{\tau}(1-\alpha))q}{r}$
Wait and see	$\frac{-k_G + \frac{(p+\alpha\bar{\tau})q}{r}}{1+r}$	$\frac{-k_F + \frac{(p-c_F)q}{r}}{1+r}$	$\frac{\left[\begin{array}{c}\phi\left(-k_G + \frac{(p+\alpha\bar{\tau})q}{r}\right) + \\ (1-\phi)\left(-k_F + \frac{(p-c_F)q}{r}\right)\end{array}\right]}{1+r}$

The third option is to wait and make an investment once it is clear whether a carbon price will be enacted. If the investor waits until after the policy is decided, assumption 1 implies that she will invest in the green asset if the tax is implemented (which happens ϕ% of the time) and the fossil asset if it is not $(1-\phi)$.

The expected profit under this approach is

$$E[\pi_{Wait}(\tau)] = \frac{\phi\left(-k_G + \frac{(p+\alpha\overline{\tau})q}{r}\right) + (1-\phi)\left(-k_F + \frac{(p-c_F)q}{r}\right)}{1+r}.$$

A share of the time equal to ϕ, the carbon tax is implemented, and she chooses to invest in the green option at capital cost k_G, earning $(p+\alpha\overline{\tau})q/r$ (recall that α is the share of the tax passed through to consumers). The other $(1-\phi)$ share of the time, no tax is enacted, and she chooses the fossil option. Because she must wait until next year to accrue all of these revenues and costs, we must discount them by 1 year (divide by $1+r$), reflecting the penalty from waiting due to the time value of money.

Note that under these assumptions, if the investor waits to make her decision, she never actually pays the tax. If the tax is implemented, she chooses the green option and avoids it (and, in fact benefits from any amount passed through to consumers). If the tax is not implemented, there is no penalty for choosing the fossil asset. Even if there is no passthrough ($\alpha = 0$), the tax still matters because it determines what the investor does in that scenario. The optimal strategy it depends on the values of the parameters. In general, wait and see is optimal if:

$$E[\pi_{Wait}(\tau)] > \max\left[E\left[\pi_{G,0}(\tau)\right], E\left[\pi_{F,0}(\tau)\right]\right] = E\left[\pi_{G,0}(\tau)\right],$$

where the latter equality follows by assumption 2 (that the green asset is preferred in expectation). Given our model, we can derive when companies will be induced to delay their investment simply due to policy uncertainty. This happens when the expected value from the wait-and-see approach is larger than the guaranteed value of simply choosing the green option from the outset:

$$E[\pi_{Wait}(\tau)] > E\left[\pi_{G,0}(\tau)\right]$$

$$\frac{\phi\left(-k_G + \frac{(p+\alpha\overline{\tau})q}{r}\right) + (1-\phi)\left(-k_F + \frac{(p-c_F)q}{r}\right)}{1+r} > -k_G + \frac{(p+\phi\alpha\overline{\tau})q}{r}$$

$$\phi(\alpha\overline{\tau}q/r) + (1-\phi)\left(-k_F - \frac{c_F q}{r}\right) > -k_G(1+r) + pq$$

$$(1-\phi)\left(k_G - k_F - \frac{c_F q}{r}\right) > -k_G r + (p+\phi\alpha\overline{\tau})q \qquad (1)$$

The left-hand side (which is positive by assumption 1, since the fossil investment is assumed to be cheaper absent the tax) is the expected savings on capital and operational costs by choosing the fossil asset in the event the tax is not enacted (which happens with probability $1-\phi$). This is the benefit from waiting—having the option to switch to the cheaper fossil asset if the tax does not materialize. If this is benefit large, the investor might be inclined to wait.

The right-hand side is net financial loss from waiting. It includes two components. The $(p+\phi\alpha\overline{\tau})q$ term represents one year of lost revenue because the investor must wait an additional year to build the plant. The $\phi\alpha\overline{\tau}$ term reflects the expected value of the tax passed through to prices, in the event that the tax is implemented. This is offset by a savings of $-k_G r$, which is the time value of the money (k_G) we saved by waiting to invest. We could put that money in the bank and earn a $r\%$ return on it, yielding us $k_G r$ by waiting. If the net of these lost revenues and saved capital costs is large relative to the expected benefit, we might be inclined to invest right away. Note that since we assume the green investment produces positive profits (revenues exceeding costs in present value terms), the net of these two is also positive. The decision to wait depends on which positive value is larger: the benefits from waiting (the LHS) or the costs (the RHS).

How can policymakers manipulate this condition to encourage immediate investment—in order words, to ensure that the inequality condition in (1), which leads investors to delay their investments, does not hold? One simple way is to credibly commit to implementing the carbon price next year—that is, announcing $\phi = 1$. Then the investor's perceived benefit of waiting vanishes (the LHS of (1) becomes zero), and the only effect of waiting is delayed profits (the RHS of (1)). With passthrough, announcing a large carbon tax also makes the lost profits from waiting (RHS side of (1)) larger by increasing the output price. Notably, this announcement guarantees accelerated investment in green assets.

By contrast, consider an alternative policy in which the government subsidizes green assets by offering an investment tax credit designed to equalize the costs of fossil and green assets in present value terms. That is, the government subsidizes the green investment such that the capital cost after subsidies to the firm is now the lower value $k'_G = k_F + \frac{c_F q}{r}$. Replacing the k_G term with this new expression similarly eliminates the value of waiting (the LHS of (1)), similarly accelerating investment. While this subsidy has the same effect in this model as a carbon pricing announcement, it requires the government to deploy financial resources, whereas the announcement does not.

A.1.2. Numerical Example

Now we parameterize this model based on values that roughly reflect the cost profiles of investments in onshore wind turbines (green) and natural gas combined cycle power plant (fossil), based on the National Renewable Energy Laboratory's (NREL) 2020 Annual Technology Baseline (ATB) report. The systems are sized to have the same expected generation of approximately 1 million MWh per year.

Table A.2. Parameters

Common Parameters		
Carbon Tax (τ)		\$60/ton CO_2
Probability of Tax (ϕ)		25%
Energy Price (p), before passthrough		\$43/MWh
Passthrough rate (α)		50%
Discount rate (r)		10%

Unit Characteristics	Green (Onshore	Fossil (Natural Gas)
Capacity	280 MW	208 MW
Capacity Factor	40.9%	55%
Generation (q)	1.003 million	1.003 million MWh/year
Emissions rate	0	0.34 tons CO_2/MWh
Carbon tax per unit of energy	\$0/MWh	\$20.38/MWh
CAPEX	\$1.60 million/MW	\$1.09 million/MW
OPEX	\$0/MWh	\$19.80/MWh
Capital Cost (k_G, k_F)	\$449 million	\$227 million
Annual Operating Cost (c_G, c_F)	\$0	\$19.80 million

Table A.3. Profits in millions of dollars, under alternative options and conditions (Maximum profit strategy in each column is shown in green)

	Profit with tax for sure	Profit with no tax for sure	Expected profit with uncertain tax
Invest green at $t = 0$	$\$84.31$	$-\$17.93$	$\$7.63$
Invest fossil at $t = 0$	$-\$95.42$	$\$6.82$	$-\$18.74$
Wait and see	$\frac{\$84.31}{1.1} = \$76.65$	$\frac{\$6.82}{1.1} = \$6.20$	$\frac{\frac{1}{4}\$84.31 + \frac{3}{4}\$6.82}{1.1} = \$23.81$

Plugging these parameter values into Table 1 results in the NPV numbers in Table 3. Under these parameters, the investor's profit-maximizing strategy under uncertainty is to delay the investment decision until it is clear whether a carbon tax is imposed. With a 25% chance, the tax is imposed, and the investor invests in the green asset, yielding \$84.31/1.1=\$76.65 (\$84.31 in present value that is discounted because it is received one year hence).

With a 75% chance, the tax is not implemented, and the investor chooses the fossil asset, yielding \$6.82/1.1. The expected profit is $\frac{\frac{1}{4}\$84.31+\frac{3}{4}\$6.82}{1.1} = \$23.81$. This dominates the $-\$18.74$ in expected losses from the fossil asset (which reflects the probability weighted average of the $-\$95.42$ present value loss with the tax and $\$6.82$ gain without it: $\frac{1}{4}(-\$95.42) + \frac{3}{4}\$6.82 = -\$18.74$) as well as the $\$7.63$ in expected profit from the green asset (which in turn is the probability weighted average of the $\$84.31$ in gain with the tax and $-\$17.93$ loss without it).

The uncertainty leads the investor to delay any investment at all so that she can wait and see if the fossil asset might be preferred. If the government were to make clear from the start that the tax will be implemented, the investor will jump to immediately invest in the green asset.

A.2. Infinite Horizon Extension

The two-period model above is a simplification. Most importantly, it assumes a very simplified structure of carbon tax uncertainty: either the tax is implemented in year 2, or it is not, and the policy never changes after that. However, carbon taxes, once implemented, are typically adjusted over time. Specifically, we extend the model to allow the carbon tax to vary every year forever, while also allowing the investor to wait indefinitely to make their decision.

We use the same conceptual profit function as two period model, but allowing for time-varying taxes:

$$\pi_{G,t} = -k_G + \sum_{h=1}^{\infty} \frac{(p+\alpha\tau_{t+h})q}{(1+r)^h} = -k_G + \frac{pq}{r} + q\alpha \sum_{t'=1}^{\infty} \frac{\tau_{t+h}}{(1+r)^h} > 0 \qquad (2)$$

$$\pi_{F,t} = -k_F + \sum_{h=1}^{\infty} \frac{\big(p - c_F - \tau_{t+h}(1-\alpha)\big)q}{(1+r)^h} = -k_B + \frac{(p-c_F)q}{r} - q(1-\alpha)\sum_{h=1}^{\infty} \frac{\tau_{t+h}}{(1+r)^h} \qquad (3)$$

Now τ_{t+h} is subscripted by time. τ_{t+h} is a random variable representing the tax h years ahead, and in each year it can take on one of three values: $\tau_{t+h} \in \{0, \tau_M, \tau_H\}$. That is, the tax is either zero, <u>m</u>odest, or <u>h</u>igh. While τ_t is known at time t, future values are unknown to the investor, who must then form expectations based on the (known) probabilities around tax movements over time.

The probability that next year's tax is any given value, based on today's value, is governed by a transition matrix denoted Φ:

$$\Phi = \begin{bmatrix} \phi_{00} & \phi_{0M} & \phi_{0H} \\ \phi_{M0} & \phi_{MM} & \phi_{MH} \\ \phi_{H0} & \phi_{HM} & \phi_{HH} \end{bmatrix}$$

In general, the (i, j) element of Φ, represents the probability of moving from state i today to state j next year. For example, ϕ_{00} represents the probability that there will be be no tax next year, given that there is no tax today. ϕ_{MH} represents the probability that the tax will be raised from a modest level today to a high level next year. And ϕ_{HH} represents the probability that an existing high tax stays in effect next year. Note that the rows must sum to 1, since the tax must either be zero, modest, or high next year.

We might think that implementing a tax at all is difficult (ϕ_{00} is close to 1) but that once implemented taxes are difficult to repeal (ϕ_{M0} and ϕ_{H0} are small, or even zero) and taxes, once implemented, tend to be increased over time (ϕ_{MH} large).

This means that even if a tax itself is modest, it could signal to investors that higher taxes are likely to come in the future, which in turn affects expectations around the projected costs of alternative investments.

In any given period, the value function, as a function of the tax rate that period is

$$V(\tau_t) = \max\left\{E\left[\pi_{G,t}\middle|\tau_t\right],\ \ E\left[\pi_{F,t}\middle|\tau_t\right],\ \frac{1}{1+r}E[V(\tau_{t+1})|\tau_t]\right\}. \qquad (4)$$

With partial passthrough ($\alpha \in (0,1)$), both green and fossil asset's profits are stochastic through the tax rate (see last term in equations (2) and (3)). The linearity of the profit function in τ_{t+h} means that the expectation of each year's tax rate can be written in closed form as a function of expected taxes, which in turn are simple probability weighted averages of the three possible tax rates, where the probability weights are uniquely determined by Φ.[1] This means that for a given set of parameters, everything in equation (3) is known except the shape of the value function $V(\tau_t)$. We can solve this through value function iteration.

All input assumptions are the same as in the two-period model, except we add additional nuance to the potential carbon prices and their transition probabilities:

$$\tau_t \in \{0, \$10, \$98\} \text{ per ton}$$

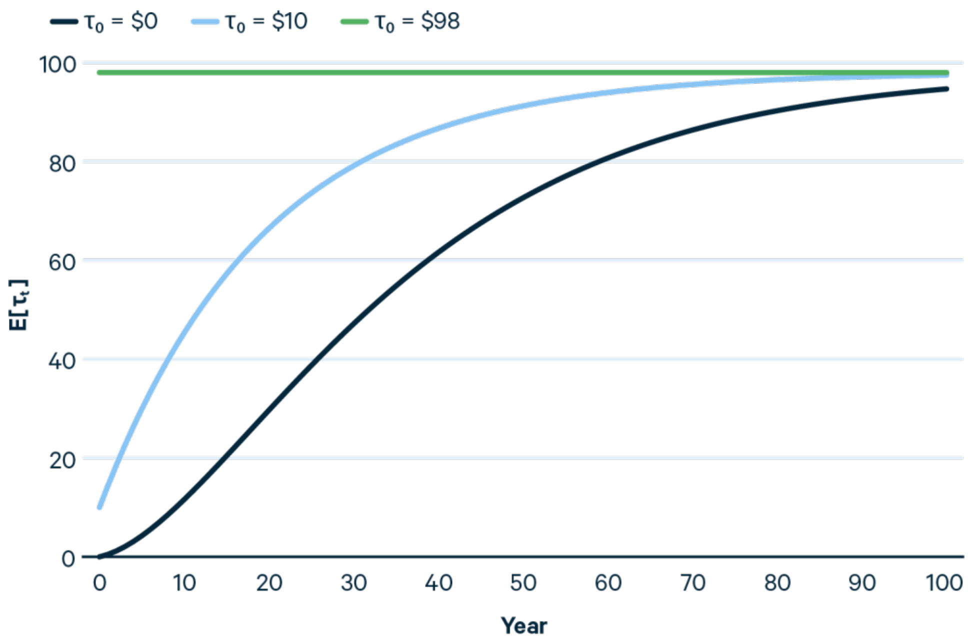
$$\Phi = \begin{bmatrix} 0.95 & 0.05 & 0 \\ 0 & 0.95 & 0.05 \\ 0 & 0 & 1 \end{bmatrix}$$

The \$98 high rate corresponds to Kaufman et al. (2020)'s estimate for the tax rate in 2030 required for global net zero emissions to be achieved by 2050. The \$10 rate is a stand-in for a "low" carbon tax, and falls roughly between prices in the California (around \$17) and RGGI (around \$7) cap and trade programs. These parameters imply an expected tax rate that evolves over time according to Figure 1.

This is a strongly persistent tax. A no-tax state is followed by another no-tax state with 95% probability. The same is true for a modest tax state. The modest tax is raised to a high tax with a 5% probability. Once the high tax is achieved, it is a permanent, absorbing state. Thus, a high tax is inevitable, but it takes a while to get there.

[1] In particular, the expected tax rate in period $t+h$ given the current rate is $i \in \{1,2,3\}$ corresponding to $\{0, M, H\}$ is given by $E[\tau_{t+h}|\tau_t = \tau_i] = \sum_{j=1}^{3} \Pr\left(\tau_{t+h} = \tau_j|\tau_t = \tau_i\right)\tau_j$ where the conditional probability is $\Pr\left(\tau_{t+h} = \tau_j\middle|\tau_t = \tau_i\right) = (\Phi^h)_{i,j}$, which is the (i,j) entry of Φ^h, which is the Φ matrix multiplied by itself h times.

Figure A.1. Implied Expected Carbon Tax over Time ($E[\tau_t]$), Starting from Each State $\tau_0 \in \{0, \$10, \$50\}$



The results are shown in Tables 4 and 5. The profit-maximizing strategy in each row (state of the world) is shown in green. Table 4 shows the profits as seen (incorrectly) by a myopic investor, who assumes today's conditions will perpetuate forever. Such an investor will invest in fossil if they believe there will never be a tax (Table 4, column 1), will not invest in anything at all if the tax will be modest forever (Table 4, column 2, which are both negative NPVs), and only invests in green once the high tax is in effect (Table 4, column 3).

Table 4. *Myopic* Profits (millions of dollars) and Strategies in Infinite Horizon Model (Maximum profit strategy in each column in green)

	Currently No Tax ($\tau = \$0$)	Currently Modest Tax ($\tau = \$10/ton$)	Currently High Tax ($\tau = \$98/ton$)
Invest green	$-\$18$	$-\$0.9$	$\$149$
Invest fossil	$\$7$	$-\$10$	$-\$160$

Table 5. Profits (millions of dollars) and Strategies in Infinite Horizon Model (Maximum profit strategy in each column in green)

	Currently No Tax ($\tau = \$0$)	Currently Modest Tax ($\tau = \$10/ton$)	Currently High Tax ($\tau = \$98/ton$)
Invest green	$\$7$	$\$54$	$\$149$
Invest fossil	$-\$18$	$-\$65$	$-\$160$
Wait and see	$\$18$	$\$53$	$\$135$

By contrast, Table 5 shows the profits as seen (correctly) by a forward-looking investor. Such an investor waits for the policy signal to invest at all (column 1, Table 5), and then invests in green *even before* it is seen as immediately profitable (compare column 2 in Tables 4 and 5).

Even though the green investment is NPV positive at a tax of zero, it is nonetheless better to wait for a more favorable policy environment. Therefore, without a tax, the investor will wait for a policy signal. Once a modest $10 carbon price is enacted, the green option becomes the best option. This is largely not driven by the $10 price itself (see Table 4, showing that for a fixed $10 tax the green investment loses money), but rather by the fact that it creates a discrete change in the expected path of future carbon prices (which are partially passed through into output prices, thereby boosting the profitability of green investments) due to expectations of the tax being raised to $98/ton in the future. Similarly, the fossil investment would be strongly NPV-positive in perpetuity under a permanent $0 tax, but the forward-looking investor recognizes that future policy will render the investment unprofitable (compare column 1 in Tables 4 and 5).

A.2.1. Non-Durable Policies

Another interesting case if where we change the transition matrix to consider policy durability, such as where modest prices are likely to remain in place or be strengthened, but poorly designed prices are non-durable and hence likely to be cut or repealed. This is represented by the transition matrix:

$$\Phi = \begin{bmatrix} 0.95 & 0.05 & 0 \\ 0 & 0.95 & 0.05 \\ 0.50 & 0.25 & 1 \end{bmatrix}$$

The new path of expected carbon prices is as shown in Figure 2, and the resulting profits and optimal strategies are shown in Table 6. Interestingly, the threat of repealing a high tax implies that medium-term expected carbon prices are in fact higher when we currently have a $10 tax than when we have a $98 tax, as the latter is likely to be repealed.

Now it is only rational to invest in the green asset when the tax is modest, as that is the scenario with the highest path of future carbon prices. The likelihood that a high tax might be imminently repealed leads investors to “wait and see”. This highlights the importance that a policy be seen as durable.

Figure A.2. Implied Expected Carbon Tax over Time ($E[\tau_t]$), Starting from Each State $\tau_0 \in \{0, \$10, \$50\}$, "Non-Durable Policy" Transition Probabilities

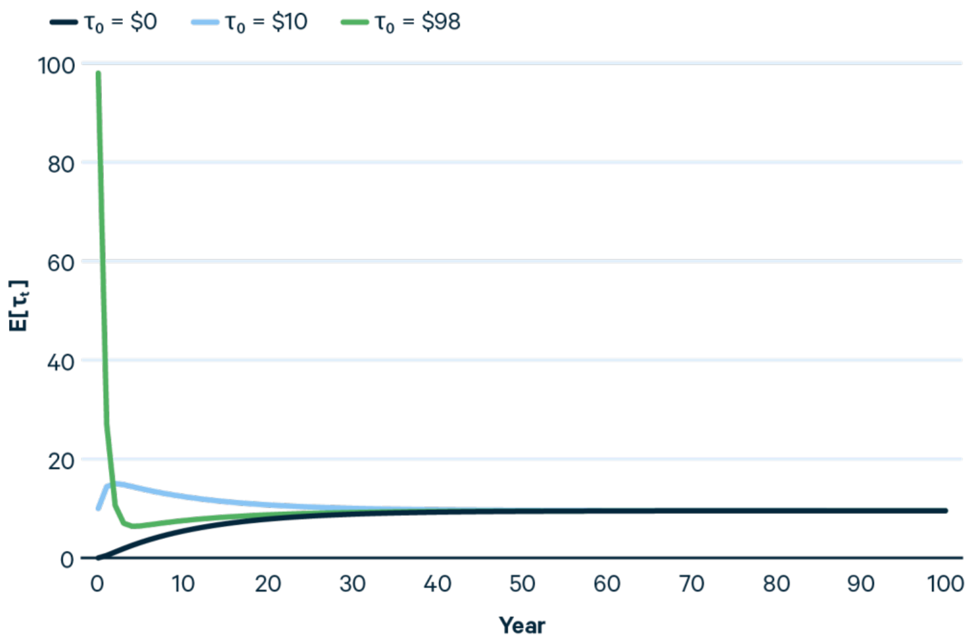


Table A.6. Profits (millions of dollars) and Strategies in Infinite Horizon Model (Maximum profit strategy in each column in green), under "Non-Durable Policy" Scenario

	Currently No Tax ($\tau = \$0$)	Currently Modest Tax ($\tau = \$10/ton$)	Currently High Tax ($\tau = \$98/ton$)
Invest green	$-\$10$	$\$39$	$-\$1.5$
Invest fossil	$-\$1$	$-\$15$	$-\$10$
Wait and see	$\$1.3$	$\$3.4$	$\$1.9$

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