ADDING QUANTITY CERTAINTY TO A CARBON TAX THROUGH A TAX ADJUSTMENT MECHANISM FOR POLICY PRE-COMMITMENT

Marc Hafstead,[*] *Gilbert E. Metcalf,*[**] *& Roberton C. Williams III*[***]

INTRODUCTION

Carbon taxes and cap-and-trade programs are emissions-pricing policies that create incentives to reduce harmful greenhouse gas ("GHG") emissions.[1] These policies raise the price of fossil fuels (the burning of which emits GHGs into the atmosphere), inducing businesses and consumers to substitute away from those fuels and thereby reduce emissions. Economists agree that emissions pricing is the most cost-effective method to reduce GHG emissions.[2]

The choice between a carbon tax and a cap-and-trade program is less clear-cut. Both policies price emissions, but how that price is set is very different. Carbon taxes directly set the emissions price, while the level of emissions is determined by market forces. In contrast, cap-and-trade programs set the overall level of emissions (via the number of permits issued) and allow the market to set the price. In the absence of uncertainty, this distinction doesn't matter: policymakers could either pick the price to achieve the (known) quantity of emissions desired, or set the quantity of allowable emissions and let the market determine the (identical) price. If macroeconomic levels or abatement costs are uncertain, however, the two policies could have very different ex post outcomes.[3]

An extensive literature within economics addresses the relative efficiency of these two policy instruments in the presence of uncertainty.[4] Here, we focus on a different question:

---

[*] Fellow, Resources for the Future. We wish to thank Ray Kopp for helpful input on earlier drafts, Christopher Holt for excellent research assistance, and RFF's Center for Energy and Climate Economics for financial support for this work.

[**] Professor, Tufts University; Affiliated Researcher, Resources for the Future; NBER.

[***] Professor, University of Maryland; Senior Fellow and Director of Academic Programs, Resources for the Future; NBER.

[1] A carbon tax is an example of Pigouvian pricing, where a tax is levied on pollution-causing activities equal to their marginal social damages. *See generally* ARTHUR C. PIGOU, THE ECONOMICS OF WELFARE (1932). In the absence of other distortions, this is socially efficient. J.H. Dales is credited with developing the idea of cap-and-trade as an alternative to Pigouvian pricing. *See* J.H. DALES, POLLUTION, PROPERTY, AND PRICES (1968).

[2] A poll of prominent economists taken by the Initiative on Global Markets at the University of Chicago Booth School showed that 90% of the economists polled (95% when weighted by each expert's confidence in his/her answer) agreed or strongly agreed with the statement that a carbon tax would be a less expensive way to reduce carbon-dioxide emissions than would a collection of other policies such as fuel economy requirements for automobiles. Initiative on Global Markets Forum, *Carbon Tax*, UNIVERSITY OF CHICAGO BOOTH SCHOOL (Dec. 20, 2011), https://perma.cc/ZZY7-FC8N.

[3] The seminal paper comparing and contrasting the two instruments in a world with uncertainty is Martin L. Weitzman, *Prices vs. Quantities*, 41 REV. ECON. STUD. 477 (1974).

[4] *See generally* Lawrence H. Goulder & Ian W.H. Parry, *Instrument Choice in Environmental Policy*, 2 REV. ENVTL. ECON. & POL'Y 152 (2008); Cameron Hepburn, *Regulation by Prices, Quantities, or Both: A Review of Instrument Choice*, 22 OXFORD REV. ECON. POL'Y 226 (2006).

how could one design a carbon tax that can provide a level of certainty with respect to quantity as well as price?

To be clear, our focus in this paper is a narrow one. We simply ask how one could design a carbon tax with a mechanism to reduce uncertainty about future emissions, and what tradeoffs different design elements might entail. We do not evaluate whether there is an economic efficiency argument to be made for such a mechanism; we leave that for future research. The normative question of whether a carbon tax *should* include such a mechanism is even further beyond the scope of the Essay. However, if the politics of climate policy are such that adding greater emissions certainty to a carbon tax facilitates its passage, then it is worthwhile to examine how that mechanism might be designed, what its key elements would be, and what modeling might be undertaken to better understand the implications of such a policy design.

With that as background, we define and discuss the design elements for a Tax Adjustment Mechanism for Policy Pre-Commitment ("TAMPP"). A TAMPP is an adjustment mechanism for a carbon tax rate to ensure that targeted emission reduction milestones are met over the decades following implementation.

Part I places the TAMPP in the context of a rich literature on price, quantity, and hybrid instruments in GHG emissions policy design. In Part II, we enumerate key design questions that must be considered when designing a TAMPP. Part III focuses on how the economics modeling community might design new or adapt existing models to assess a carbon tax with a TAMPP feature.

I. POLICY DESIGN FOR CARBON PRICING

While much of the discussion over instrument choice for carbon policy has been over the relative merits of price (e.g., tax) or quantity (e.g., allowance) instruments,[5] hybrid instruments have received less attention. A hybrid instrument adds elements of a price instrument to a quantity instrument or vice versa. A price collar is the archetypal hybridization of a cap-and-trade system; it combines a price ceiling in a cap-and-trade system with a price floor, thus limiting the magnitude of price increases or decreases.

However, with a price collar or a variant in which permits could be sold from a reserve, we no longer have certainty over cumulative emissions. Under a price collar, if the price hits the floor, the government buys back permits at that price, thus reducing the level of emissions allowed. If the price hits the ceiling, the government sells additional permits, thus increasing emissions. Sales from a permit reserve have a similar effect.[6,7] Thus, the hybrid system adds some elements of a price system to the existing cap-and-trade system.

Given the focus on design elements to reduce price volatility in a cap-and-trade system, an obvious question is whether an analogous hybrid is possible for a price

---

[5] *See* Hepburn, *supra* note 4; Weitzman, *supra* note 3.

[6] Reserves are discussed in Brian C. Murray et al., *Balancing Cost and Emissions Certainty: An Allowance Reserve for Cap-and-Trade*, 3 REV. ENVTL. ECON. & POL'Y, 85–92 (2009).

[7] We note in passing that the argument that cap-and-trade provides certainty over emissions is somewhat illusory. Even in the absence of a price collar or some similar mechanism, Congress serves as the ultimate implicit price ceiling. Were prices to rise to levels unanticipated and unacceptable, Congress could simply legislate a relaxation of the cap to bring prices down to more politically and economically acceptable levels.

instrument in order to reduce ex post uncertainty over emissions under a carbon tax. Surprisingly little research has been undertaken on this question.[8] Metcalf's Responsive Emissions Autonomous Carbon Tax ("REACT") has the following features:

- An initial tax rate and standard rate of growth for the tax is set at the outset.
- Benchmark targets for cumulative emissions are set for a control period, which could be one year, five years, ten years, or some other time interval.
- If cumulative emissions exceed the benchmark targets at the specified interval, the growth rate of the tax is increased to a higher rate until cumulative emissions fall to or below their benchmark targets in subsequent years.[9]

Metcalf runs some simple simulations to illustrate how the mechanism could operate, but does not do an in-depth assessment of the mechanism.[10] Nor does he discuss design principles or possible variations in design for the consideration of policy makers. We turn to such a discussion in the next section. But before doing so, we pause to consider what sorts of "uncertainty" are relevant for the analysis.

At its most basic level, uncertainty refers to the deviation of some quantity of interest from the level that was anticipated when the policy was implemented.[11] That quantity of interest could be an outcome (such as allowance prices or emission levels) or something that influences those outcomes (such as the overall level of economic activity).

As discussed in the Introduction to this Symposium,[12] there are three types of uncertainty related to future levels of emissions. First, unexpected changes in the level of the overall economy (either caused by changes in long-term growth or by business-cycle fluctuations) will impact future emissions levels. Second, policymakers may set the emissions price too low or too high, reflecting uncertainty in the aggregate marginal abatement costs at the time of implementation. Finally, the marginal abatement costs may shift dramatically over time due to new technology.

II. DESIGN CONSIDERATIONS FOR A TAMPP

The basic structure of a TAMPP is straightforward. A time profile of tax rates is set over a control period, and a final emissions target and intermediate benchmarks are set. If, at specified times during the control period, emissions deviate sufficiently from the intermediate benchmarks, the tax rate changes in order to bring emissions back toward the benchmarks. For example, if emissions exceed the benchmark target, the tax rate would adjust upward.

Figure 1 provides a schematic for a TAMPP. The tax is enacted at time zero and a final target is set for some designated future date T. Interim benchmarks are set where emissions (annual or cumulative; or emission reductions) are compared to the benchmark

---

[8] We are aware of only one paper on this topic: Gilbert E. Metcalf, *Cost Containment in Climate Change Policy: Alternative Approaches to Mitigating Price Volatility*, 29 VA. TAX REV. 381 (2009).

[9] *See id.* at 391–92.

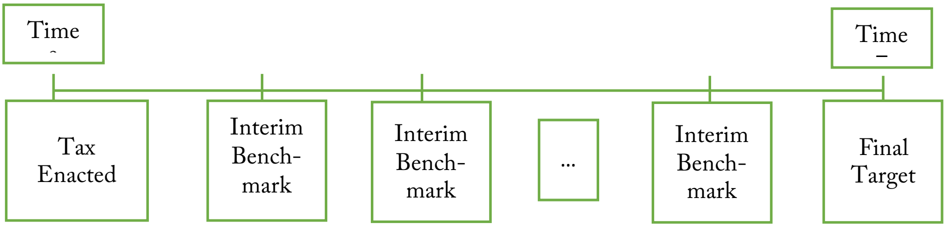
[10] *See id.* at 395–99.

[11] We are abstracting away from volatility. While price volatility is of particular concern with a cap-and-trade system, emissions volatility is less of a concern given the stock nature of GHG pollution.

[12] Josephy E. Aldy et al., *Resolving the Inherent Uncertainty of Carbon Taxes: Introduction*, 41 HARV. ENVTL. L. REV. F. 1 (2017).

and the tax rate is adjusted as needed. These adjustments should be designed so that the final target is likely to be achieved.

Figure 1. TAMPP Schematic



The Swiss Carbon Tax Law provides a simple example of a TAMPP policy.[13] The tax, which covers emissions from electricity and heating, had an initial rate of twelve Swiss francs ("CHF") per metric ton of CO_2 in 2008 and 2009; by 2012, the tax rate had been raised to thirty-six CHF.[14] The law specifies that if emissions in 2012 were greater than seventy-nine percent of 1990 emissions, the tax rate would increase to sixty CHF as of January 1, 2014.[15] The law specifies two additional milestone years (2014 and 2016) with tax rates to adjust (in 2016 and 2018, respectively) if the milestones were not met.[16] The law put in place two different higher tax levels for 2016 and 2018 depending on the level of emissions.[17] The tax would rise to ninety-six CHF in 2018, for example, if emissions exceeded seventy-three percent of 1990 emissions. But the tax would rise to 120 CHF if emissions exceeded seventy-six percent of 1990 emissions.[18]

The Swiss Carbon Tax Law is only one example of the structure that a TAMPP could take. Current policy proposals often include TAMPP-like elements, such as the Whitehouse-Schatz American Opportunity Carbon Fee Act of 2015, which imposed an annual two percent (over inflation) increase in the tax rate until emissions fall to eighty percent below 2005 levels, after which the tax rate would grow at the rate of inflation.[19] Policymakers face a number of key design choices in adding a TAMPP to a carbon tax.

---

[13] For an overview of the Swiss carbon pricing policy, *see* PETER SOPHER & ANTHONY MANSELL, ENVTL. DEF. FUND & INT'L EMISSIONS TRADING ASS'N, THE WORLD'S CARBON MARKETS: A CASE STUDY GUIDE TO EMISSIONS TRADING: SWITZERLAND (2013), https://perma.cc/PJF4-D9VQ.

[14] *See id.* at 2. The carbon tax was initially enacted as part of the 1999 Act on the Reduction of CO_2 Emissions and covered emissions between 2008 and 2012. It was subsequently revised to cover emissions through 2020. Firms could opt out of the carbon tax by participating in the Swiss Emissions Trading System. *Id.* at 1–2.

[15] *Ordonnance sur la Reduction des Emissions de CO_2* [Ordinance on the Reduction of CO_2 Emissions] Dec. 23, 2011, RS 641.711, art. 94 (Switz.), https://perma.cc/MV7R-ZZJP.

[16] *Id.*

[17] *Id.*

[18] *Id.*

[19] S. 1548, 114th Cong. §4691 (2015).

A. Rules vs. Discretion

Policymakers face a trade-off between setting hard rules for tax changes versus allowing for policy discretion. The advantage of rules is that they can provide confidence that future Congresses won't pull back on a commitment to making promised cuts in emissions. Discretion, on the other hand, provides flexibility to future Congresses to take account of new information in a welfare-improving way.

Changes to the carbon tax rate to ensure that targets are met during the compliance period could be preemptively spelled out in legislation (a rules-based approach) or left to Congress to periodically make as needed (a discretion-based approach).[20] The effectiveness of the mechanism will turn on the ease with which appropriate adjustments can be implemented over time in the face of political uncertainty or administrative obstacles. Another possibility would be for Congress to delegate the tax-setting authority to an executive branch agency such as the Department of the Treasury ("Treasury"), Environmental Protection Agency ("EPA"), or a new quasi-independent agency similar to the Federal Reserve. But congressional delegation of tax-setting authority to another branch of government might not be constitutional[21] and history suggests that even if it were constitutional, Congress would not willingly delegate such authority.[22]

Excluding delegation, tax rate changes must either be specified in legislation (as in the Swiss carbon tax example) or periodically enacted by Congress in response to new information about emissions. The latter approach would make the TAMPP simply a guide for future Congresses; it is unlikely that this would assure constituents that want guarantees that a carbon tax can achieve certain emissions targets.

Specifying the changes in legislation would be somewhat unusual, because future tax rates would be dependent on future emissions, and there are relatively few cases in the U.S. in which legislation specifies changes to future tax rates based on events that are not specific to the affected taxpayer. But some examples do exist. Many dollar amounts in the tax code are automatically adjusted for inflation,[23] applicable federal rates (interest rates used in the tax system, which determine, for example, the interest charged on tax underpayments) are set based on market rates for Treasury bills and bonds,[24] and the tax credit available to a hybrid car buyer is based on how many hybrid vehicles the car's manufacturer had previously sold.[25]

---

[20] Joseph Aldy proposes a process in which the President recommends an adjustment to the carbon tax, and Congress holds an up-or-down vote on the recommendation. *See generally*, Joseph E. Aldy, *Designing and Updating a U.S. Carbon Tax in an Uncertain World*, 41 HARV. ENVTL. L. REV. F. 28, 31–34 (2017).

[21] James R. Hines & Kyle D. Logue, *Delegating Tax*, 114 MICH. L. REV. 235, 268 (2015) (arguing that the Supreme Court would probably uphold the constitutionality of delegation of tax-setting authority, but also noting that the issue has not yet been directly tested).

[22] *Id.* at 235 (reviewing congressional history and concluding that Congress "tightly limits the scope of Internal Revenue Service . . . and Treasury regulatory discretion in the tax area, specifically not permitting these agencies to select or adjust tax rates").

[23] *See* 26 U.S.C. § 1(f) (2012).

[24] *Id.* § 1274 (2012).

[25] *Id.* § 30D (2012).

B. TAMPP Control Period

Over what period should the TAMPP apply? We argue that, while climate policies (e.g., a carbon tax) ought to be imposed on a permanent basis, the time period for which the TAMPP applies will be limited by the lack of information regarding the future state of emissions, abatement technologies, and damages from climate change.

Most climate policy discussions focus on the near term (e.g., 2025 to 2030 for most of the Intended Nationally Determined Contributions ("INDC") submitted to the U.N. Framework Convention on Climate Change ("UNFCCC") in the run up to the 2015 Conference of the Parties ("COP") in Paris) while also articulating longer-term goals (e.g., 80% reduction in emissions by 2050). The U.S., for example, committed in its INDC to "an economy-wide target of reducing its GHG emissions by [26–28%] below its 2005 level in 2025" while noting that its target "is consistent with a straight line emission reduction pathway from 2020 to deep, economy-wide emission reductions of 80% or more by 2050."[26]

While a permanent carbon tax is desirable, the TAMPP control period—the length of time over which emissions targets are set—should be finite in duration. The final target year needs to be sufficiently far into the future that meaningful long-run investments contributing to lower emissions can be justified. However, it cannot be so distant that any of the policy's conjectures about the state of technology and energy networks, or about future emissions reductions needs, become overly speculative. Interim targets will have to be set throughout the control period, and the further out in time the control period extends, the more difficult it is to set those targets.

On the other hand, setting a control period of only a few years reduces incentives for long-lived energy investments necessary to reach a zero-carbon economy. The Swiss carbon tax is a good example. With a control period that extends only to 2020,[27] it is difficult to see how the law will provide incentives for significant additional reductions in the post-2020 era.

In general, the longer-lived the relevant investments, the longer the control period must be. And the more uncertainty we have about how the costs and benefits of carbon mitigation will evolve over time, the shorter the control period should be. Pinning down a specific number is difficult, but it should be at least ten to fifteen years in order to overlap with U.S. international commitments to meet certain emissions targets under the UNFCCC.[28] However, it is hard to imagine how to credibly set targets more than thirty-five to forty years into the future. Modeling could provide greater guidance as to the optimal length of the control period and we offer this as one item in a broader research agenda on flexible and responsive environmental tax design.

This discussion has assumed a specific end date for the control period. One could also imagine an endogenous length of control whereby the control period ends once an

---

[26] U.S. COVER NOTE, INDC AND ACCOMPANYING INFORMATION, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (2015), https://perma.cc/9RHK-8RED.

[27] *Ordonnance*, *supra* note 15.

[28] We are not suggesting that the TAMPP should be designed specifically to reflect U.S. commitments made through the UNFCCC process. There are good reasons to enact a carbon tax and include a TAMPP component regardless of the state of UNFCCC negotiations. But the TAMPP targets should not be inconsistent with any timetable developed as part of the UNFCCC negotiating process.

emissions threshold has been achieved. After that date, the tax rate might be fixed, rise at the rate of inflation, or increase at a relatively slow rate above the rate of inflation. Under this approach, it would still be useful to have at least an approximate target end date in mind for transparency and clarity in business planning.

The importance of the length of the control period also depends on the likely timing of future legislation. If we were certain that an updated law would be enacted in ten years, then any targets beyond ten years would matter only as a guideline for future laws, so the distinction between a twenty-year versus fifty-year control period would be relatively unimportant. In contrast, if the law is infrequently revisited, then targets further into the future become more important.

C. Targets and Interim Benchmarks

Emissions targets and interim benchmarks, which define the policy's environmental goals and measure progress toward those goals, should be set and designed in a consistent and easily quantifiable manner. Targets can be set in terms of emissions relative to some base year, some absolute emissions cap, or emissions reductions relative to a business-as-usual ("BAU") baseline. The first type of target is consistent with the 2025 target articulated in the U.S. INDC. It is a percentage reduction relative to emissions in 2005 and thus indirectly sets an absolute cap on emissions in 2025. The second approach would simply make the cap explicit and is consistent with the approach taken in the annual allowance allocations in the Waxman-Markey cap-and-trade bill passed by the U.S. House of Representatives in 2009.[29] The third type of target is consistent with the approach that many nations have taken with their INDCs (e.g., South Korea's INDC calls for a 37% reduction below BAU by 2030).[30]

In addition, interim benchmarks could be set in terms of annual emissions, cumulative emissions, or some moving average of emissions. Carbon dioxide is a stock pollutant—damage is caused by the total stock of carbon dioxide in the atmosphere, not the flow of new emissions each year.[31] Therefore, a longer-term target (cumulative emissions or a moving average over a relatively long period) more closely corresponds to what determines damages. Using a moving average rather than an annual snapshot would prevent the tax from adjusting to short-term fluctuations potentially caused by an abnormally cold or warm winter or by economic recession and expansion during a normal business cycle. Setting benchmarks in terms of cumulative emissions would further prevent price volatility because a single period's emissions would not significantly alter the total level of emissions over the control period.

How much smoothing (reductions in realized price volatility) is desirable depends on the persistence of unexpected shocks. If all shocks persist forever (i.e., if the underlying

---

[29] H.R. 2454, 111th Cong. §703 (2009). Given the ability to bank allowances from previous years, the Waxman-Markey annual declining allowance allocation is not the same as an absolute cap.

[30] For information on specific nations, see INDC AND ACCOMPANYING INFORMATION, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (2015), http://perma.cc/2WFG-NCB4.

[31] Thomas F. Stocker et al., *Technical Summary*, *in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 33, 50–52 (Thomas F. Stocker et al. eds., 2013).

quantities follow random walks), then smoothing provides no advantage and simply causes adjustments to lag unnecessarily behind the shocks. In such a case, adjusting based on the most recent emissions would be ideal. In contrast, if all shocks are very transitory, then smoothing is desirable: in this case it doesn't affect the likelihood of hitting the final target, and avoids unnecessary price volatility.

In practice, there will be a mix of transitory and persistent shocks: for example, business-cycle and weather shocks are transitory, whereas technology shocks will be more persistent. The ideal design would allow benchmark quantities to cover a long enough period to smooth out the transitory shocks, but a short enough period to respond quickly to persistent shocks.

Targets and benchmarks specified as reductions from a BAU emissions path raise a number of difficult questions. How is the BAU path set? How often is it updated to reflect changes in the BAU economy? Who updates the path and according to what model? Should the BAU path closely reflect what actual BAU emissions would be or is it simply a benchmark against which to assess reductions? We see little if any advantage to setting targets or benchmarks in terms of emission reductions from a hypothetical BAU path, no matter how accurately one believes such a path could be estimated.

Despite the problems of setting targets and benchmarks relative to a BAU path, it is important to emphasize that the costs of reducing emissions depend on the legislated emissions trajectory (however specified) relative to the BAU emissions pathway. For example, the costs of reducing emissions to a given target would depend on whether, in the absence of policy, the world experienced breakthroughs in low- or zero-cost carbon technologies.

Regardless of how targets and benchmarks are defined, the number of interim benchmarks should be set to reasonably assure stakeholders that the final target will be achieved. However, as we note below, while frequent adjustments of tax rates are beneficial, such adjustments could occur between benchmark years. If adjustments occur between benchmark years, there would be no strong economic rationale for choosing the number of interim benchmarks. If not, more frequent interim benchmarks would be preferable.

D. Types of Adjustments

Depending on when adjustments are made, policymakers must also determine how to adjust the carbon tax if interim targets are not met. Adjustments to the tax rate could take a variety of forms. One approach would be to specify tax rates (dollars per ton of CO_2) in the legislation with schedules contingent on whether interim benchmarks have been met. This is the approach taken in the Swiss Carbon Tax Law.[32]

Metcalf suggests an alternative approach. A tax rate is specified for the first year along with an annual percentage increase in the tax rate. If cumulative emissions at an intermediate milestone exceed the target specified for that year, the annual rate of increase in the tax rate jumps to a higher level until cumulative emissions at a future benchmark no longer exceed the benchmark target. For illustrative purposes, Metcalf suggests a

---

[32] *Ordonnance*, *supra* note 15.

"standard" tax growth rate of four percent (above inflation) and a higher "catch-up" rate of ten percent (above inflation).[33]

One might combine elements of the Swiss approach and the Metcalf approach. The TAMPP might specify two or more percentage increases in the tax rate for the next control period that depend on the amount by which emissions exceed some targeted level.

Clarity and certainty in the rules for tax rate adjustment are vital to ensure that the business community can plan with reasonable certainty. Adjustments to either the level of the tax or the rate of growth can be designed to provide both clarity and certainty and there is no obvious economic argument to pick one approach over the other. As discussed below, political intervention may occur if the policy prescribes large increases in the tax rates, therefore adjustments to the rate of growth rather than the tax level may be politically desirable.

E. Frequency and Size of Adjustments

A TAMPP policy must specify how often to adjust the tax rate and the size of those adjustments. The two are closely linked: the more frequent the adjustments, the smaller each adjustment should be, with the size of each adjustment being roughly proportional to the period between adjustments. Several small adjustments will add up to the same overall effect as one large adjustment, so if adjustments occur half as often, each one will need to be roughly twice as large.

Smaller and more frequent adjustments will tend to provide both lower costs and better environmental outcomes.[34] More frequent adjustments allow the tax rate to respond to new information sooner, which both improves cost-effectiveness (the most cost-effective price path incorporates new information instantly) and makes it easier to hit a given target. Larger adjustments also raise the risk of substantial price movements and political push-back.

The frequency of adjustment need not be fixed to the period defined by interim benchmarks in the legislation (if any). If, for example, the policy specifies five- or ten-year interim benchmarks, the legislation could define more frequent adjustments to allow for responses to shocks that occur during years between benchmarks. Adjustments occurring between benchmark years would then be based on smoothing between the benchmarks.[35]

However, there are practical limits to adjustment frequency. For example, adjustments cannot be made more frequently than emissions data is updated. More frequent updating could also raise enforcement and compliance costs, though this likely would be a significant issue only with very frequent updating (e.g., monthly or quarterly).

---

[33] *See* Metcalf, *supra* note 8, at 395.

[34] Louis Kaplow and Steven Shavell explain that inefficiencies arise when a policy is constrained to imposing a fixed (linear) tax rate, where allowing a tax rate to vary with the magnitude of economic harm (say, damages caused by global warming) induces an optimal reduction in the regulated externality. Frequent adjustments in the TAMPP would allow for a policy that more closely resembles the optimal nonlinear design. *See* Louis Kaplow & Steven Shavell, *On the Superiority of Corrective Taxes to Quantity Regulation*, 4 AM. L. & ECON. REV. 1, 3–7 (2002).

[35] The initial response of the economy to a tax could make smoothing between benchmark years problematic in the first few years of the policy. This could be an argument for not making any adjustments in those first few years.

For a given frequency of adjustment, the size of adjustments pose a tradeoff: larger adjustments make it more likely that emissions will stay close to the target quantities, but would likely also imply higher costs.[36,37] Very large tax rate adjustments can also undermine political credibility as they increase the chances that Congress might intervene to inhibit policy implementation. In the end, a balance must be struck between an adjustment process that provides credibility in the environmental outcomes and a process that does not lead to abrupt and large economic costs.

Given the above, we would expect the most frequent adjustments to occur annually. At the other end of the continuum, decadal adjustments seem too infrequent. The Swiss model of two-year interim targets is not unreasonable. In the end, this comes down to a tradeoff between economic and environmental factors, which favor more frequent adjustment, versus practical and political considerations that could push in the opposite direction.

F. Adjustment Trigger

The adjustment trigger is the policy mechanism that determines when a tax adjustment will be made based on the relationship between actual emissions and a benchmark interim target. For example, if emissions exceed the interim target by some designated amount, then the policy design may call for an increase in the tax rate intended to affect a decrease in emissions closer to the benchmark target.

Adjustment trigger design considerations include, among other things: whether the trigger is one- or two-sided; whether it is discrete or continuous; and whether there is a range for deviations from the target. A one-sided trigger only responds to undershooting the target (e.g., cumulative emissions exceeding the allowed level) by raising the tax rate. A two-sided trigger would add a provision for reductions in the tax rate (or rate of growth of the tax rate) in the case of overshooting the target (as in the case of a technology shock that significantly reduces abatement costs). We see no particular reason for choosing a one-sided trigger over a two-sided trigger.

Triggers could be discrete or continuous. Metcalf proposes a discrete two-sided trigger where the tax rate grows at a standard rate of four percent above inflation but then jumps to ten percent above inflation if emissions exceed the target.[38] It then reverts to the four percent growth rate when emissions fall below subsequent targets. The Swiss ordinance is an example of a one-sided target, as there is no provision for lowering the rate at any adjustment period.[39] The Swiss ordinance also illustrates the possibility of multiple discrete adjustments depending on emissions deviations from the target.[40]

---

[36] This tradeoff depends on how elastic emissions are with respect to the tax rate, with a lower elasticity implying a need for larger adjustments. This means that uncertainty about that elasticity is especially problematic when designing the policy.

[37] Large adjustments could also lead to overshooting and oscillations where we alternately fall short of and exceed the target. An adjustment that is a function of the gap between emissions and the target as discussed in the next sub-section could reduce the potential for overshooting.

[38] *See* Metcalf, *supra* note 8, at 395.

[39] *See Ordonnance*, *supra* note 15.

[40] *See id.*

Adjustments could also be continuous. Tax rate changes could be a function of the deviation of emissions from the target. As a simple example, the percentage change in the tax rate (Δ) might equal:

$$\Delta = max\left(1.0, \alpha\left(\frac{E-T}{T}\right)\right)$$

where α is some positive constant, *E* is the measure being tracked, and *T* is the target. This example puts a cap of 100 percent on the tax rate increase at any given adjustment benchmark. So, if α were set to ten, an overshoot of three percent in the measure *E* relative to its target would lead to an increase in the tax rate of thirty percent. Note that the formula could be made symmetric for undershooting the target (e.g., if *E* were three percent lower than *T*, there would be a thirty percent decline in the tax rate), asymmetric (the value of α could depend on whether $E > T$ or $E < T$), or one-sided (α equals zero when $E < T$). One could also use a more complex formula, such as a nonlinear function.

A continuous adjustment will generally be more cost-effective and better from an environmental standpoint, since it will imply smoother and more predictable changes in tax rates over time (if emissions are near the cutoff for a discrete adjustment, a small change in emissions could produce a big change in the tax rate). But this advantage might be small, especially if the adjustments are frequent and relatively small in magnitude.[41] Further, politicians may view such a continuous adjustment mechanism as too complex and opaque.

The threshold for triggering a tax rate change could be based on the target itself or a band around the target. Above, we have described thresholds where the tax adjusts if emissions exceed the target. An alternative mechanism might trigger adjustments if emissions exceed some band around the target (e.g., exceeding the target by more than two percent). One example is a tiered threshold, based on color coded bands: a narrow green band around the target requires no action; a wider yellow band serves warning that the target is being exceeded and action may be required in the future (or that leads to an immediate but modest tax change). The mechanism could also require action if too much time is spent in the yellow band, and an immediate increase in the tax rate (or a larger tax change than would occur in the yellow band) if emissions reach even wider red band.

IV. AN AGENDA FOR RESEARCH ON TAMPPS

Research on TAMPPs would be useful, both for evaluating different design choices under a TAMPP and for comparing a TAMPP to other alternative policies (e.g., a carbon tax without any formal adjustment mechanism or a cap-and-trade program). But as noted earlier, we are aware of only one paper that addresses any portion of this issue in the climate context: Metcalf's 2009 paper about REACT, a specific example of a TAMPP (see section II for details of the REACT policy).[42] That paper includes some simple simulations, but

---

[41] If adjustments are discrete, the same reasoning strengthens the argument for smaller, more frequent adjustments.

[42] A theoretical paper by Ermoliev et al. considers how an environmental agency could adjust prices through an iterative procedure to achieve desired pollution targets using prices. Its focus is a flow pollutant (e.g., acid rain). It does not address a stock pollutant like GHG emissions. *See* Yuri Ermoliev et al., *Adaptive Cost-Effective Ambient Charges Under Incomplete Information*, 31 J. INT'L ENVTL. ECON. & MGMT. 37 (1996).

they are intended to be illustrative, not to provide rigorous modeling of the REACT policy. In this section, we outline some of the useful directions that research on TAMPPs might take, as well as some of the challenges such research would face.

A good starting point would be simple analytical modeling. Weitzman's 1974 paper comparing price and quantity regulations and much of the literature that followed it have used simple analytical models. Such models have major advantages in transparency and generality of results. They can also put a sharp focus on key underlying forces that drive important economic results. Weitzman's simple modeling structure, for example, highlighted the importance of the relative slopes of the marginal damage and marginal benefit curves for emissions in determining whether price or quantity instruments are ex ante more efficient.

But as analytical models become more complex, they soon become intractable. Uncertainty and dynamics are essential for modeling a TAMPP, and those elements together lead to inherently complex models. Moreover, reaching quantitative conclusions is likely to require numerical simulations. Thus, we believe that while research might start with analytical models, numerical simulation will quickly become necessary.[43]

One could attempt to model the underlying structure of the economy and energy sectors in detail, in a manner similar to the computable general equilibrium ("CGE") models that are commonly used to model the response of carbon emissions and the broader economy to the introduction of a carbon price. Indeed, an existing CGE model could be the core of a numerical model to evaluate a TAMPP.

The major problem with such an approach is that CGE models are almost all deterministic, and uncertainty is obviously a vital element of any model used to evaluate a TAMPP. A common approach to handling uncertainty in CGE modeling is to undertake Monte Carlo analysis with deterministic CGE models. Monte Carlo approaches assume probability distributions for key parameters. For upwards of 10,000 replications, parameters are drawn from the distributions and model simulations are conducted to produce a distribution of key results such as levels of emissions by year.[44] Such an approach is useful for illustrating model sensitivity to key parameters and could be used to estimate uncertainty over the marginal abatement cost curve at the time of policy implementation. However, this methodology would fail to address other types of uncertainty arising from unexpected shocks over time. This highlights the internal inconsistency of Monte Carlo

---

[43] Papers on dynamic problems in the literature on policy instrument choice under uncertainty typically use numerical simulation (often in addition to analytical models). *See, e.g.*, Michael Hoel & Larry Karp, *Taxes Versus Quotas for a Stock Pollutant*, 24 RES. & ENERGY ECON. 367 (2002); *see also* William A. Pizer, *The Optimal Choice of Climate Change Policy in the Presence of Uncertainty*, 21 RES. & ENERGY ECON. 255 (1999). The modeling in Metcalf 2009 was entirely numerical. Metcalf, *supra* note 8.

[44] Webster et al. take such an approach in modeling with a global climate model that includes a CGE model of the world economy as one element of the broader model. Mort Webster et al., *Uncertainty Analysis of Climate Change and Policy Response*, 61 CLIMATIC CHANGE 295, 305 (2003). Jan Abrell and Sebastian Rausch use a Monte Carlo experiment to characterize uncertainty in marginal abatement costs curves for ETS and non-ETS sectors in Europe. Jan Abrell & Sebastian Rausch, *Combining Price and Quantity Controls under Partitioned Environmental Regulation*, 145 J. PUB. ECON. 226 (2017).

analysis: Monte Carlo simulations explicitly incorporate uncertainty but the underlying models have no uncertainty.[45]

Adding explicit uncertainty to an existing CGE model or building a new CGE model with explicit uncertainty would be a tremendous undertaking.[46] Thus, using a CGE model directly is likely infeasible, though CGE models could be useful for parameterizing other approaches.

Dynamic stochastic general equilibrium ("DSGE") models are another potentially promising approach. They have primarily been used to study macroeconomic problems, but are starting to be used in environmental applications. Such models include dynamics and uncertainty, but the tradeoff is that they have greatly simplified representations of the structure of the economy, typically modeling only a single aggregate sector, and almost never modeling more than two or three sectors.[47] This greatly limits their ability to represent the range of carbon emissions abatement options needed to provide meaningful insight into the GHG mitigation problem. Nonetheless, a properly parameterized DSGE model could be very useful for modeling a TAMPP by providing a framework that properly addresses the uncertainty in the business cycle and uncertainty in shocks to future abatement costs.

A simpler approach wouldn't try to model the underlying structure of the economy at all, but would instead take a much more reduced-form approach. In such an approach, emissions would be a function of the carbon tax rate (perhaps representing the speed of adjustment to tax changes by also including the rate from one or more previous time periods), with random shocks to the level and slope of that function. This is the approach that Metcalf took.[48]

A major challenge for either of the latter two approaches—DSGE or reduced-form—is parameterizing the response of emissions to a carbon price. Key elements that would need to be parameterized include how much emissions respond to a given price (i.e., the

---

[45] A further difficulty with Monte Carlo analysis is determining what probability distributions to use for the key parameters. In many cases, there is no empirical evidence, and so such distributions must rely on ad hoc assumptions. This problem isn't unique to Monte Carlo analysis, though; it (or very similar problems) apply to every method for handling uncertainty discussed in this section.

[46] In deterministic models, agents choose actions each period to maximize some objective function. In a stochastic model, agents actions are governed by a decision or policy rule that governs which actions to take conditional on different realizations of a shock. Often, this rule will be non-linear, and yet solution methods for non-linear stochastic models almost always use first or second order approximations. Further, most of these approximation methods are only useful if the economy is close to its steady state and are not appropriate for solving transitions from one steady state to another, as would be the case with a carbon tax. Moreover, these approaches are very computationally intensive, and thus other aspects of a CGE model would likely need to be substantially simplified in order to make analysis with explicit uncertainty computationally tractable.

[47] *See* Anna Grodecka & Karlygash Kuralbayeva, *The Price vs. Quantity Debate: Climate Policy and the Role of Business Cycles* (Centre for Climate Change Econ. and Policy, Paper No. 201, Grantham Research Inst. on Climate Change and the Env't, Paper No. 177, 2015); Garth Heutel, *How Should Environmental Policy Respond to Business Cycles? Optimal Policy Under Persistent Productivity Shocks*, 15 REV. ECON. DYNAMICS 244 (2012); Francesca Dilusio, Environmental Policy and the Business Cycle: The Role of Adjustment Costs on Abatement (2016) (unpublished manuscript), https://perma.cc/F74J-9GNS.

[48] Metcalf, *supra* note 8, at 396.

elasticity of the abatement supply curve), how quickly that response occurs,[49] and how random shocks could alter that response.[50] We don't have direct empirical estimates of any of those elements, because the U.S. has never imposed a national carbon price (and even if one extrapolates from experience in other countries that have imposed a carbon price, the sample is quite small).

One could use the results from a CGE model (or models) to parameterize emissions response to a carbon price. This approach would run the CGE model for a range of different carbon tax rates (to measure the emissions response to the tax), trajectories for the tax (to measure the speed of adjustment), and underlying model parameters (to measure how random shocks could change the response)—in essence, running a Monte Carlo analysis along these dimensions. This still relies upon the CGE model providing a reasonable representation of the emissions responses to carbon pricing, but since the CGE model includes more of the underlying structure of the economy and energy sector, its parameters can be estimated based on a wider range of historical shocks to the economy.[51]

Even if parameterized based on a CGE model, however, the reduced-form approach has the fundamental problem that it cannot represent the effects of firms anticipating future carbon tax adjustments. Suppose emissions are well above the target under the TAMPP, and a firm is considering making a long-term investment that will lower its carbon emissions. Because emissions are high, future tax adjustments under the TAMPP will almost certainly raise the tax rate, thus making that long-term investment look more attractive than it would look based just on the current carbon price. That kind of anticipation of tax changes will generally make the TAMPP perform better (more likely to hit emissions targets, and in a more cost-effective way), and thus failing to capture it in a model will bias the results.[52] A DSGE model has the potential to avoid this problem, since it can explicitly capture firms' anticipation of future tax changes.

Under any of these approaches, empirical research on the uncertainty about future emissions paths would be important. As noted earlier (in Section II), we see three key sources of uncertainty: 1) unexpected shifts in BAU emissions; 2) errors in estimates of the marginal abatement curve at the start of the policy; and 3) unexpected shifts in that marginal abatement curve over time. The first of these—shifts in BAU emissions—is

---

[49] Some adjustments will be almost immediate, such as changes in the dispatch order for electric power generation by existing plants, while other responses could take decades, such as retirement of long-lived emissions-intensive capital.

[50] The simulations in Metcalf, *supra* note 8, at 396, use a function that implicitly assumes away the latter two elements. In that model, emissions respond immediately to a change in the carbon tax, and there is no uncertainty about the magnitude of that response; the BAU level of emissions is uncertain, but the reduction a given carbon tax rate will cause from that BAU level is entirely deterministic. Metcalf parameterizes the function based on runs of the EPPA CGE model.

[51] For example, substitution elasticities among different energy sources in a CGE model could be estimated using events that caused exogenous shifts in relative prices of different energy sources (such as shocks to the world oil market), but those same prior events would not be sufficient for directly estimating the reduced-form response of emissions to a carbon tax.

[52] If short-term shifting of emissions is possible, then anticipation could also make the TAMPP perform worse. A firm that anticipates a carbon tax increase at the start of next year and can do short-term shifting of emissions would shift emissions from next year into this year. This would incur some costs, but do nothing to lower cumulative emissions. But because the potential for such shifts seems smaller than the importance of long-lived investments, anticipation seems likely to boost the performance of a TAMPP rather than hurt it.

straightforward to estimate based on prior data. Nonetheless, we are unaware of empirical work that has explicitly focused on the magnitude and persistence of random shocks to BAU emissions. Such estimates would be valuable for designing and evaluating any policy designed to manage uncertainty about carbon abatement.

The second and third sources of uncertainty are harder to estimate, however, because they can only be directly observed after a carbon pricing policy is in place, and there are relatively few cases of carbon pricing to work with. But those cases might be enough to provide some lessons, or it might be possible to draw information from pricing of emissions other than carbon. Some work in this area already exists,[53] and further research could be highly useful.

Summing up, we see a fruitful research agenda for incorporating uncertainty into CGE modeling. First, we see great value in doing more Monte Carlo simulations with existing CGE models. While this approach has an internal inconsistency in that these models assume economic agents are making decisions in a world without uncertainty, the approach still has value. It sheds light on where reducing parameter uncertainty can be most fruitful in reducing error bars on key model results and can highlight the extent of the uncertainty surrounding the marginal abatement curve at the start of the policy. But it cannot answer many key questions about TAMPP mechanisms because a deterministic CGE model cannot adequately model future shocks that would lead to TAMPP adjustments.[54]

Second, building new or adapting existing DSGE models to study climate policy should have a high priority in the research agenda. While the models will need to be simplified in many ways to be computationally tractable, even simple DSGE models have the potential to tell us quite a bit about how adaptive policy (such as a TAMPP) interacts with risk preferences and uncertainty. Simple DSGE models could also provide useful insight as to the size and direction of biases that come from running Monte Carlo simulations with deterministic CGE models.[55]

At the same time that a research program to incorporate uncertainty explicitly into CGE modeling proceeds, there is a need to inform policy makers on near term policy initiatives. Deterministic CGE models can be used to determine what initial tax rate and price path would lead to a given target. This is simply an ex ante estimate based on the assumptions in the model and should not be construed as "truth;" in other words, how emissions actually decline for a given ex ante price path will differ due to errors in the

---

[53] For example, Kaufman et al. find that estimates prior to the introduction of carbon pricing tend to overestimate marginal abatement costs, thus leading either to overestimates of permit prices under cap-and-trade or underestimates of abatement under an emissions tax. *See* NOAH KAUFMAN, MICHAEL OBEITER & ELEANOR KRAUSE, WORLD RES. INST., PUTTING A PRICE ON CARBON: REDUCING EMISSIONS (2016), https://perma.cc/5P2G-W94S.

[54] Note that agents could still react to anticipated future policy in these models if the models incorporate forward looking behavior. This is distinct from the observation that the CGE models that would be used for these Monte Carlo runs have economic agents that operate as if the world is deterministic. But the models cannot incorporate reactions to shocks. Or, in other words, agents in these models can react to policy changes that are entirely predictable before the policy starts, but not to any other policy changes (such as TAMPP adjustments caused by unexpected changes in BAU emissions or in the abatement cost curve).

[55] Some have called for a "third wave" of climate modeling, including the use of DSGE models. *See* J. Doyne Farmer et al., *A Third Wave in the Economics of Climate Change*, 62 ENVTL. & RES. ECON. 329 (2015); Nicholas Stern, Commentary, *Current Climate Models Are Grossly Misleading*, 530 NATURE 407 (2016).

estimation of the marginal abatement costs and unexpected shocks and may require the TAMPP to come into play if the emissions path is sufficiently off the ex ante target.

CONCLUSION

Including a TAMPP into a carbon tax could provide some assurance to the public that U.S. policy is committed to meaningful GHG emission limits (as laid out in the TAMPP).

While some design elements are a matter of legislative preference, other design elements are quite important if the policy is to be successful at its goal of providing assurance without adding inefficient or other unintended elements to a carbon tax.

In particular, any TAMPP should be built into the legislation rather than left to agency discretion. While future Congresses always have the ability to alter previous legislation, policy inertia favors making the TAMPP a default in the carbon tax legislation. How far into the future the target TAMPP emission target is set (and at what level) is a matter of judgment. Setting final target dates too far into the future risks setting targets with speculative (at best) knowledge about the state of the economy or mitigation technologies that will be available at that future date. Conversely, setting final target dates just a few years out does not provide sufficient time for meaningful emission reduction targets.

Both final targets and interim benchmarks are best designed either as absolute emission limits or as reductions from a benchmark year. While the true effect of any GHG mitigation policy is the emissions reduction from the BAU emissions path, and the true cost depends on reductions from the BAU path, this BAU path cannot be directly observed or determined with certainty (even ex post). Furthermore, the ultimate concern for measuring damages from GHG emissions is the stock of emissions in the atmosphere resulting from the accumulation of annual emissions. So, benchmarks that relate to actual emission caps (or reductions from a given historic emissions level) relate more directly to future damages.

Policymakers have considerable discretion in how they design the tax rate adjustment if interim targets are not met. Clarity and certainty in the rules for the tax rate adjustment are critically important, so that the businesses and individuals can respond with reasonable confidence to likely future government policy.

There is no set guidance for how frequently interim benchmarks should be assessed. More frequent adjustments will generally lead to lower costs and better environmental outcomes, but practical and political considerations will limit the frequency of adjustment. A similar tradeoff applies for using a discrete or continuous adjustment. The continuous adjustment will generally be superior on economic and environmental grounds, but those advantages could be small (particularly with frequent adjustments) and the apparent simplicity of discrete adjustments is a political advantage.

Finally, policymakers have considerable flexibility as to how to design other elements of the trigger. It can be one-sided or two-sided; can be designed in absolute or percentage terms; and can include the use of bands (representing deviations from the target) with different responses within each band.

Further research can provide guidance on the optimal design of a TAMPP. Here, we have laid out a research agenda that can contribute to better-informed carbon tax design in the face of uncertainty over future emission trajectories, damages, and mitigation technology.