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Incentives for early adoption of carbon capture technology: further considerations from a European perspective

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Abstract

This note details two comments on a recent policy proposal in Comello and Reichelstein (2014) aimed at favoring the early adoption of Carbon Capture (CC) technology in the next generation of thermal-based power plants to be installed in the United States. First, we examine the implications of a worst-case scenario in which no new CC is adopted internationally beyond what is in place in 2014. Second, we show the potential under the original proposed subsidy for the emergence of a coordination game capable of hampering the desired early CC deployment. We propose and evaluate modified schedules of tax-credits sufficient to overcome these concerns. These additions strengthen the argument in the original article: namely, though higher incentive levels are necessary, our findings confirm that the cost of the proposed policy is not out of reach.

Keywords: Tax incentives, Carbon Capture and Storage, Learning effects, Levelized cost.

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Introduction

The prohibitively high cost of Carbon Capture (CC) technology for first-of-a-kind plants is recurrently cited as a major barrier to its large-scale deployment. To overcome this problem, Comello and Reichelstein (2014) recently articulate an innovative policy proposal to enable substantial cost reductions by leveraging the sizeable deployment of thermal-based power generation projected in the U.S. during the period 2017-2027. The proposal combines two ingredients: a binding and inflexible emission standard; and the "*Accelerated Carbon Capture Deployment*" (ACCD) – a preannounced schedule of Investment Tax Credits (ITC) and Production Tax Credits (PTC) – aimed at providing an incentive for newly built power plants in the U.S. to adopt CC immediately.

This brief note extends the analysis by considering two issues. In a first section, we apply the framework detailed in the original article[1] to generate a schedule of tax-credits that is robust to alternative scenarios for CC deployments outside the U.S. In a second section, we reflect on the possible emergence of a coordination game capable of hampering the desired early deployment of that technology and propose a modified schedule of tax-credits that is sufficient to overcome that problem.

1 – The role of early CC deployments outside the U.S.

Using a list of proposed but still undecided projects (GCCSI, 2013), the authors assume the installation of nearly 3 GW of foreign CC capabilities between 2014 and 2020. However, in Europe, the funding of large CC projects has recently proven to be difficult causing delays and several project cancelations (Lupion and Herzog, 2013). As early foreign projects are posited to engender international spillovers, one may wonder whether these withdrawals could undermine the proposal's success.

To render the proposal robust to the vicissitudes impacting foreign projects, we consider a 'worst-case' scenario whereby foreign deployments are restricted to the unique Canadian 130MW power plant finalized in 2014. To compensate for the absence of foreign early investments, augmented ITC and PTC schedules are needed (cf., Figure 1) but our evaluations confirm that this robust version is almost as attractive as the initial version:[2]

[1] The two authors must be praised for having made their data and spreadsheet model readily available to readers.

[2] For the sake of brevity, this note solely summarizes our main conclusions. Further details on the methods used to generate the results are provided in a Supporting Document to be disseminated as a companion file to this paper.

- The Levelized Cost of Electricity (LCOE) obtained with a facility that becomes operational by the end of 2027 is approximately 7.9 ¢/kWh if CC technology is consistently adopted by all the newly built U.S. thermal power plants.[3]

- The magnitude of the tax-credit levels remain politically acceptable (cf., Figure 1).

- Overall, the cumulated (undiscounted) foregone tax revenue to the U.S. Treasury reaches about $8.2 billion.[4] This robust schedule of incentives thus represents a cost-effective solution for achieving a large scale deployment of this innovative technology.

Figure 1. The modified ACCD tax credits schedule under a robust scenario
[INSERT FIGURE 1 ABOUT HERE]

2 – Strategic interactions among CC adopters

Recent European literature on CC and storage has highlighted the interactions that exist among CC adopters connected to a common infrastructure system (Mendelevitch, 2014; Massol, et al., 2015). In the present paper, infrastructure issues are neglected but the use of an experience curve *de facto* generates some interactions. It is instructive to examine these interactions further.

Our discussion is structured as follows. A first subsection introduces our notation. The second subsection reviews the evaluation of the schedule of tax-credits used in the original article. The third subsection focuses on CC adoption in a given year by several players and proves that the incentives offered that year may not be sufficient to rule out the possible occurrence of a coordination game with multiple equilibria. As uniqueness is not achieved, these players may select an equilibrium where some emitters rationally prefer to delay CC adoption. As that phenomenon may jeopardize the desired policy outcomes, the fourth subsection identifies an appropriately augmented minimum level of incentives that is sufficient to overcome that issue. The last subsection reports the numerical results obtained using the associated ITC and PTC schedules. For the sake of brevity, all formal proofs are provided in a Supporting Document.

[3] This figure remains close to the 7.8 ¢/kWh obtained in the original article (Comello and Reichelstein, 2014 - Finding 3).

[4] This 25% increase over the base-case scenario reveals the positive externality provided by foreign early investments in first-of-a-kind CC plants.

A – Notation

We consider a given year t in $\{2017,...,2027\}$ and let: K_t denote the total planned capacity of all the power plants to be started during that year; and CK_t denote the cumulated CC capacity of all the plants installed during the preceding years τ with $\tau < t$.[5]

For an investor that considers installing a power plant during that year, we let: c_t^R denote the LCOE obtained in case of a 'last-minute retrofit' by the end of 2027,[6] and $c_t^N(x)$ be the continuous and strictly decreasing function that gives the LCOE if that plants adopts CC immediately given x, the cumulated CC in operation at that date.[7] The condition $c_t^R < c_t^N(x)$ is assumed to hold for any x with $x \le CK_{2017} + \sum_{\tau=2017}^{t} K_\tau$ indicating that, absent any subsidy, it is less costly to delay the adoption of CC capabilities.

In year t, we do not model the tax-credits but simply assume that their effect is to lower the LCOE measured on a power plant that early adopts CC capabilities. We let S_t be the levelized subsidy and $\tilde{c}_t^N(x) := c_t^N(x) - S_t$ denote the subsidized LCOE function.

B – The subsidy scheme in Comello and Reichelstein (2014)

Recall that the ACCD tax-credits are set so that, for a facility to be installed in a given year, it becomes advantageous to adopt CC capabilities immediately compared to retrofitting that plant by the end of 2027. The evaluation of the schedule of tax-credits presented in the original paper is detailed in an associated spreadsheet model: the "NGCC + CC Calculator" (Comello and Reichelstein, 2014). In this model, CC adoption at the maximum level is assumed in each year before t. The tax-credits are calibrated so that S_t, the levelized subsidy implemented in year t, verifies $S_t \ge \underline{S}_t$, where $\underline{S}_t$ is the threshold level:[8]

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[5] By construction, CK_t is thus equal to $CK_t = CK_{2017} + \sum_{\tau=2017}^{t-1} K_\tau$ if CC technology was systematically deployed at its maximum potential during each of the preceding years.

[6] As all power plants installed between 2017 and 2027 are forced to adopt CC by the end of that year, this LCOE figure is systematically evaluated assuming that $CK_{2017} + \sum_{\tau=2017}^{2027} K_\tau$ is the cumulated CC capacity in operation at that time.

[7] In the original paper, the effects of learning are allowed to commence only after 3GW of cumulative CC capacity has been deployed. Thus, $c_t^N(x)$ is a constant if $x < 3$ GW and is a continuous and strictly decreasing function if $x \ge 3$ GW. The discussion hereafter therefore concentrates on this second case.

[8] This definition of the threshold level has been derived from a meticulous examination of the original "NGCC + CC Calculator". A document summarizing this analysis and explaining how this threshold can be traced back in the original spreadsheet model can be obtained from the authors upon request.

$$\underline{S}_t := c_t^N\left(CK_t + K_t\right) - c_t^R, \quad \text{obtained with} \quad CK_t := CK_{2017} + \sum\nolimits_{\tau=2017}^{t-1} K_\tau \,. \qquad (1)$$

This threshold is evaluated assuming that all the plants installed during the preceding years have early adopted CC capabilities.

The authors underline that, by construction, the tax-credits prevent possible ‘deviation’ from an ‘equilibrium path’ of early CC adoption. Indeed, one can model CC adoption as a sequence of 11 irrevocable decisions whereby, in each year, a single decision-maker: (i) controls the capacity K_t, (ii) faces a binary choice with respect to the early adoption of CC capability, and (iii) is posited to have full information on the learning curve so that he knows how his own decision modifies the LCOE incurred in case of early adoption. Within this framework, the proposed schedule of tax-credits in the original article is such that adoption is decided in each year and thus provide the desired policy outcome.

C – Is that proposed subsidy sufficient?

However, the capacity forecasts and the standard plant size used by the authors together suggest that several power stations will be installed in some years (particularly during the period 2023 – 2027). As these plants are likely to be owned by independent companies, one may wonder whether, in each year t, the threshold level $\underline{S}_t$ is sufficient to induce the joint early adoption of CC capability by all players.

To address this issue, one has to examine the strategic interactions among these investors. We focus on a given year t and assume that early CC adoption has systematically been achieved during the preceding years so that $CK_t = CK_{2017} + \sum\nolimits_{\tau=2017}^{t-1} K_\tau$. We consider the situation whereby K_t the projected capacity addition in year t is shared among $n > 1$ independent players. Each player i controls a fraction α_i of that capacity with $0 < \alpha_i < 1$ and $\sum\nolimits_{i=1}^{n} \alpha_i = 1$.

Each player has to take an irrevocable decision regarding the immediate installation of CC capabilities. The decision has a binary nature and we let $\delta_i \in \{0,1\}$ denote the decision of player i, where $\delta_i = 1$ (respectively 0) indicates the early (respectively delayed) adoption of CC capabilities. The objective of each player is to <u>minimize</u> its LCOE.

As in the original “NGCC + CC Calculator”, we assume that each player knows how the LCOE incurred in case of early adoption is modified by the capacity decided at that time. Thus, under these assumptions, the LCOE incurred by a player i is as follows:

- If ‘delayed adoption’ is chosen by that player (i.e., $\delta_i = 0$), he incurs c_t^R.

- If that player decides to early adopt CC capabilities (i.e., $\delta_i = 1$), he incurs the subsidized LCOE $\tilde{c}_t^N \left(CK_t + \alpha_i K_t + \sum_{\substack{j=1 \\ j \neq i}}^n \delta_j \alpha_j K_t \right)$ which is a function of the other players' decisions in year t .

We now present a series of findings derived from the analytical developments detailed in a Supporting Document to this paper. To begin, we assume that the levelized subsidy S_t is chosen so as to verify $S_t \geq \underline{S}_t$, where $\underline{S}_t$ is the threshold level considered in the original "NGCC + CC Calculator".

Finding 1 – Any levelized subsidy S_t with $S_t \geq \underline{S}_t$, where $\underline{S}_t$ is defined in (1), is sufficient to make the strategy vector stating 'early CC adoption' for every player a pure strategy Nash Equilibrium (NE).

This finding conveys an important result as it shows that the condition $S_t \geq \underline{S}_t$, where $\underline{S}_t$ is defined as above, is sufficient to make "generalized early adoption" a NE. Sadly, the proposition below indicates that such a subsidy is not sufficient to obtain the uniqueness of that NE.

Finding 2 – The condition $S_t \geq \underline{S}_t$ where $\underline{S}_t$ is defined in (1), is not sufficient to make the strategy vector stating 'early CC adoption' for every player the unique NE.

Together, these two findings suggest that implementing a levelized subsidy that solely verifies $S_t \geq \underline{S}_t$ could lead to a coordination game with possibly several NEs.

Moreover, the selection of a NE other than the one that provides early CC adoption at level K_t in year t is a source of concern from both a static and a dynamic perspective. From a static perspective, such an equilibrium *de facto* provides a lower-than-expected level of early CC adoption that year. From a dynamic perspective, the following finding indicates that it may also have adverse consequences on the decisions to be taken in subsequent years because the proposed levelized subsidy proposed in year $t+1$ may no longer be large enough to achieve generalized early CC adoption in that year.

Finding 3 – Possible existence of a "snowball" effect: If delayed adoption were to be decided by some players in year t, a levelized subsidy S_{t+1} that verifies the condition $S_{t+1} \geq \underline{S}_{t+1}$, where

$\underline{S}_{t+1}$ is the threshold value defined in (1) for year $t+1$,[9] is not sufficient to make the strategy vector stating 'early CC adoption' for every player in year $t+1$ a pure strategy NE.

D – A remedy

Because of this possible snowball effect, one may desire that the schedule of levelized subsidies rules out any possibility for the investors in any given year t to pick up a NE that does not lead to generalized early CC adoption.

Proposition – In each year t, any tax-credits yielding a levelized subsidy S_t that verifies $S_t \geq \overline{S}_t$, with $\overline{S}_t := c_t^N\left(CK_t\right) - c_t^R$ and $CK_t := CK_{2017} + \sum_{\tau=2017}^{t-1} K_\tau$, is sufficient to make the strategy vector stating 'early CC adoption' for every player the unique NE.

As $\overline{S}_t > \underline{S}_t$, the condition $S_t \geq \overline{S}_t$ is more restrictive than the one considered in the original article. Nevertheless, one should note that this proposition holds for any number of players and any repartition of the capacity among them, which makes it preferable to opt for that larger threshold level.[10]

E – Application

This subsection reports the results obtained using this larger threshold under two capacity deployment scenarios: the original one (cf., Figure 2) and the robust one discussed in Section 1 (cf., Figure 3).[11]

Our evaluations indicate that the magnitude of the ITC levels remains similar; however, augmented PTC are needed. Under the original scenario, strictly larger expenditures for the U.S. Treasury are needed in each year which confirms that the incentives in the original article are not sufficient to obtain the desired unique equilibrium (cf., Figure 2.C). In case of a robust deployment scenario, substantially increased PTC rates are needed to guarantee the uniqueness of the NE (cf. Figure 3.B.).

Figure 2. The tax credit schedule needed to obtain a unique NE (original deployment scenario)

[INSERT FIGURE 2 ABOUT HERE]

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[9] That is $\underline{S}_{t+1} := c_{t+1}^N\left(CK_{t+1} + K_{t+1}\right) - c_{t+1}^R$ which is evaluated assuming that generalized early CC adoption has been attained during all the preceding years, i.e., $CK_{t+1} := CK_{2017} + \sum_{\tau=2017}^{t} K_\tau$.

[10] In contrast, the demonstration in a Supporting Document to this paper formally proves that, in case of a levelized subsidy S_t that verifies $\underline{S}_t \leq S_t < \overline{S}_t$, there exists at least one industrial configuration (i.e., a number of players and a distribution of the capacity K_t among them) such that the NE stating 'early CC adoption for every player in year t' is not unique.

[11] For the sake of brevity, this note solely summarizes our main conclusions. Further details on the methods used to generate the results are provided in a Supporting Document to be disseminated as a companion file to this paper.

Figure 3. The tax credit schedule needed to obtain a unique NE (robust deployment scenario)

[INSERT FIGURE 3 ABOUT HERE]

Table 1 summarizes the cumulative (undiscounted) foregone tax revenue to the U.S. Treasury under the four policy options obtained by combining the two capacity deployments scenarios with the two thresholds. *Ceteris paribus*, the cost increase generated by solely one of two effects discussed in this paper (i.e., a robust capacity deployment scenario with the original methodology, or our revised methodology with the original scenario) remains modest. In contrast, the joint presence of these two effects generate a substantial increase in the cost of that policy: about $14.1 billion. This is a 113% increase over the $6.6 billion figure obtained in the original article. Nevertheless, we believe that this cost figure remains tolerable for such an ambitious policy that would now be rendered robust to both foreign adverse events and domestic gaming issues.

Table 1. The cumulative foregone tax revenue to the U.S. Treasury under the four various situations ($ billion)

[INSERT TABLE 1 ABOUT HERE]

Conclusions

This note discusses the feasibility of the policy proposal in Comello and Reichelstein (2014). Two lines of arguments have been considered. First, we have examined the effects of early CC deployments outside the U.S. Second, we have determined that the initially proposed ACCD schedule can be insufficient to engender the desired generalized early adoption of CC capabilities because of the possible co-existence of multiple Nash equilibria. In both cases, a modified version of the policy has been proposed using the detailed cost structure developed in Comello and Reichelstein (2014). Though higher incentive levels have been obtained, our findings confirm that the cost of the proposed ACCD policy to the U.S. Treasury is not out of reach. This modified policy thus represents an interesting instrument to break the ‘vicious circle’ that currently hampers the deployment of CC technologies.

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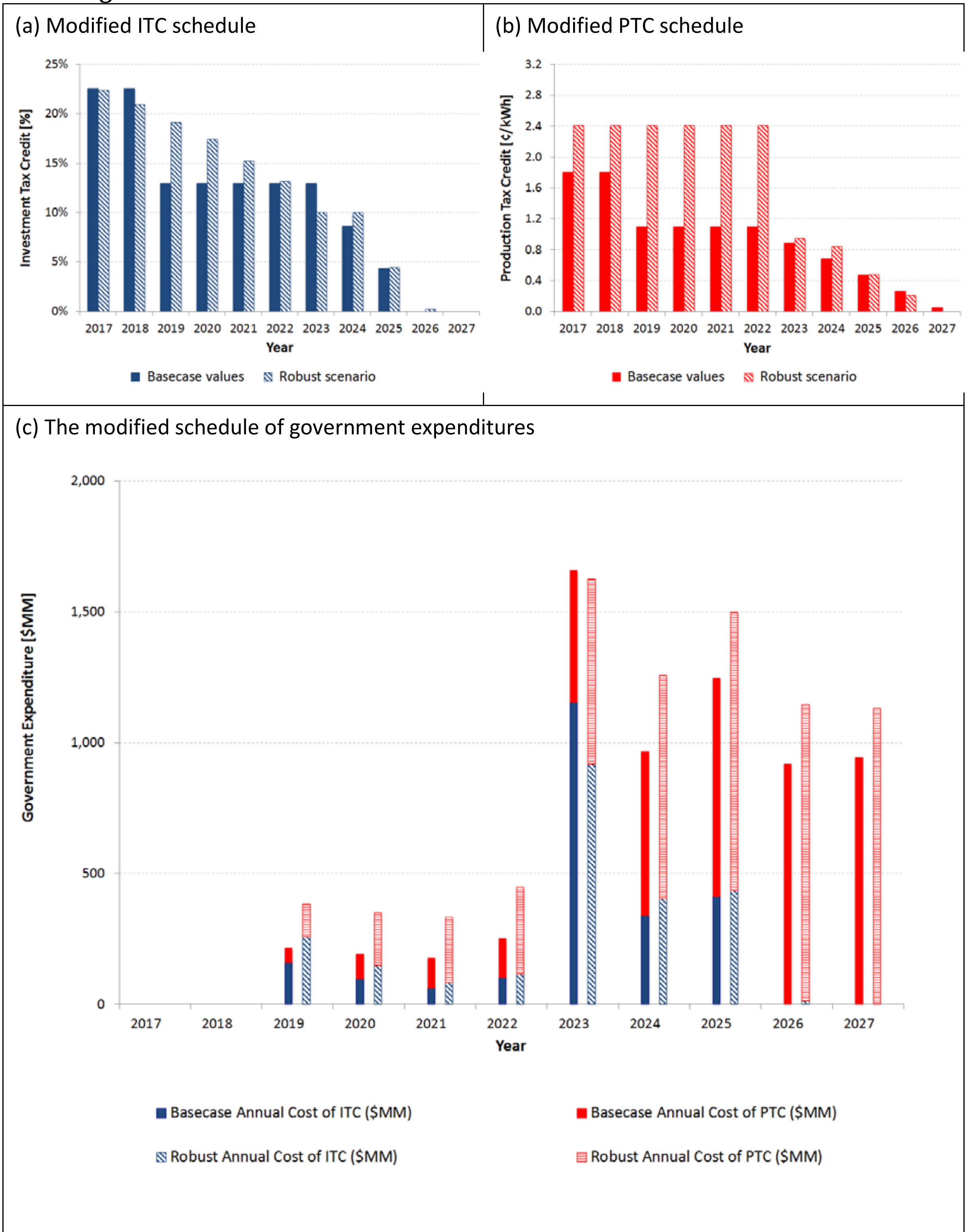
APPENDIX

Cf. the companion document.

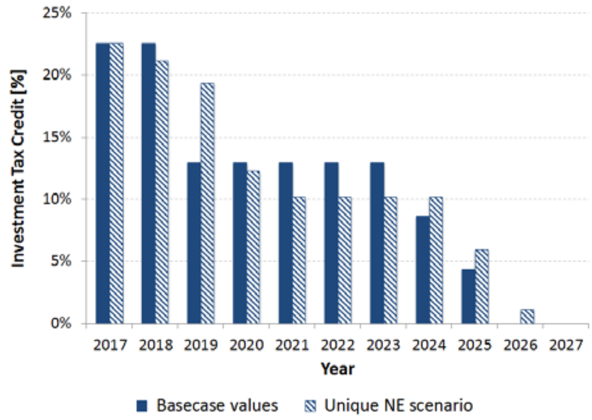
Figure 1. The modified ACCD tax credits schedule under a robust scenario



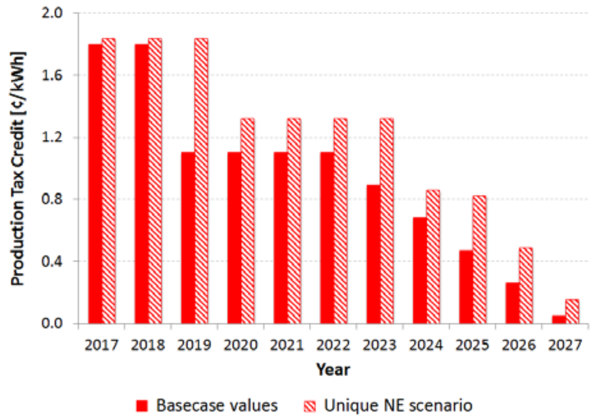
Note: These graphs compare the basecase values in the original policy proposal with the values needed in case of a robust deployment scenario. The methodology retained to evaluate these values is the one retained in the original article.

Figure 2. The tax credit schedule needed to obtain a unique NE (original deployment scenario)

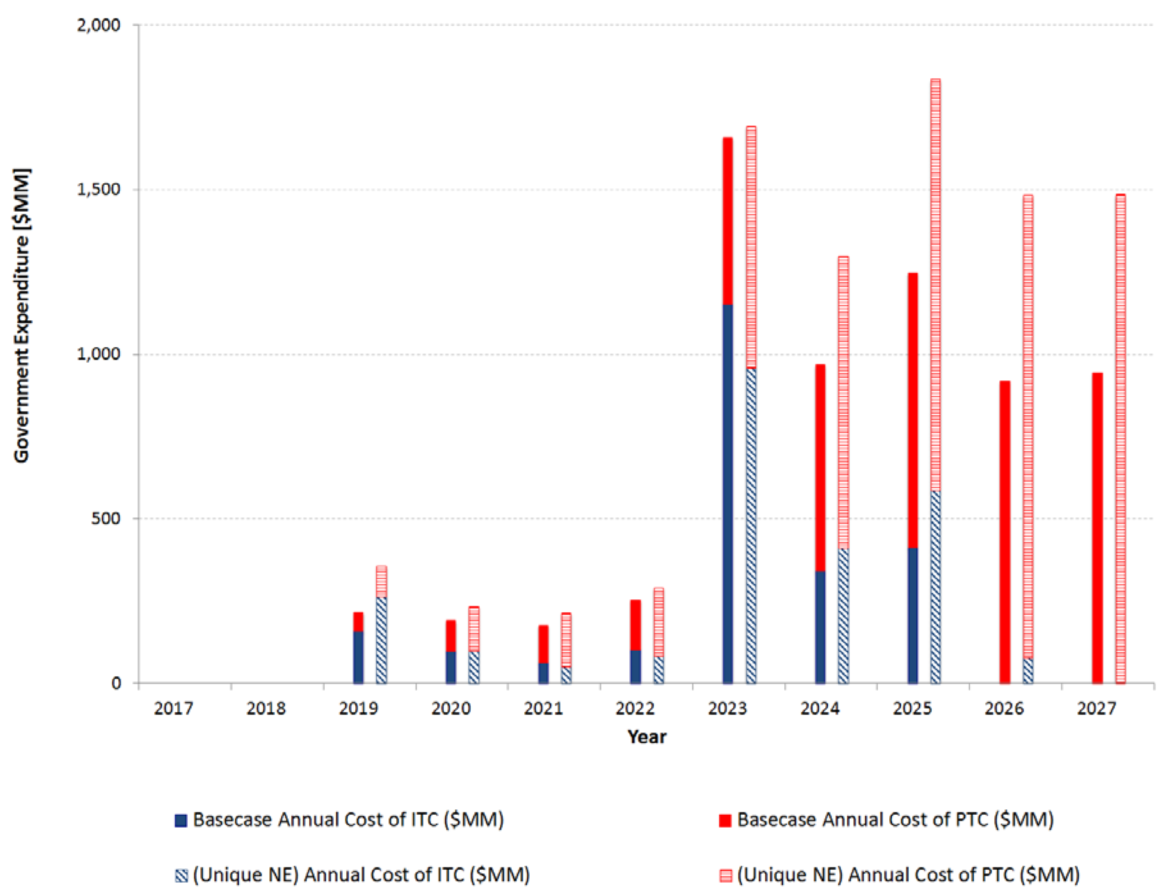
(a) Modified ITC schedule



(b) Modified PTC schedule



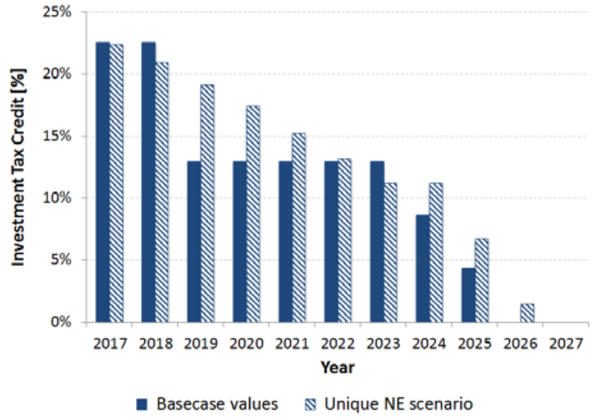
(c) The modified schedule of government expenditures



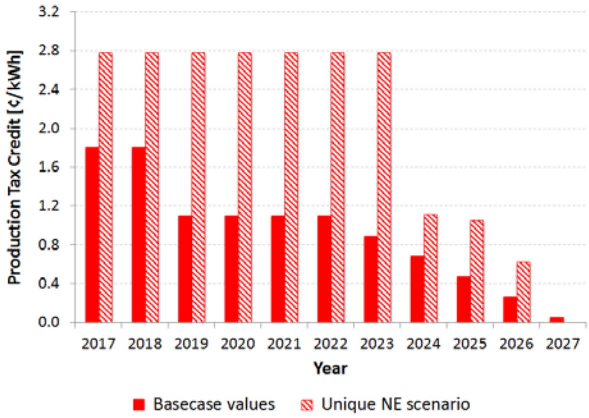
Note: These graphs compare the basecase values in the original policy proposal with the values needed to obtain a unique NE under the high CC capacity deployment scenario (i.e., the construction of nearly 3 GW of foreign CC capabilities between 2014 and 2020).

Figure 3. The tax credit schedule needed to obtain a unique NE (robust deployment scenario)

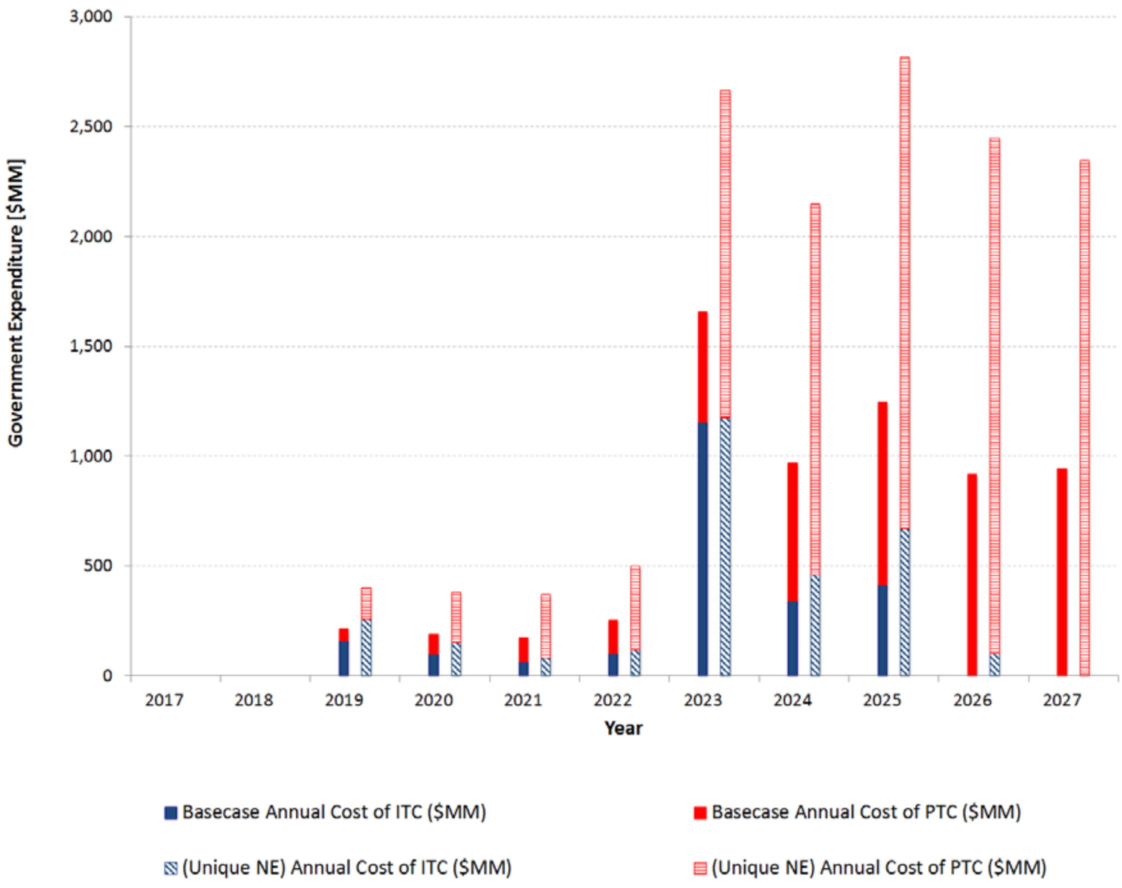
(a) Modified ITC schedule



(b) Modified PTC schedule



(c) The modified schedule of government expenditures



Note: These graphs compare the basecase values in the original policy proposal with the values needed to obtain a unique NE under the robust CC capacity deployment scenario discussed in Section 1.

Table 1. The cumulative foregone tax revenue to the U.S. Treasury under the four various situations ($ billion)

		Methodology used to determine the tax credit schedule	
		Original $S_t \geq \underline{S}_t$	"Unique NE" $S_t \geq \overline{S}_t$
CC capacity deployment scenario	Original	6.6 *	8.9
	"Robust"	8.2 **	14.1

*Note: "Robust" refers to the CC capacity deployment detailed in Section 1 and "Unique NE" refers to the new methodology discussed in Section 2.D. The asterisks * and ** respectively indicate the policy discussed in Comello and Reichelstein (2014) and the incentive policy presented in Section 1.*