Optimizing Incentives for Early Adoption of Carbon Capture in the U.S.
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Optimizing Incentives for Carbon Capture

• We discuss optimal incentives for early adoption of carbon capture technology from a U.S. perspective
  – Approach involves developing investment and production credits that provide the required incentives for new facilities to be ahead of a (proposed) capture mandate
  – Method for creating incentives for early adoption
    • Overview of the data, assumptions and methods proposed by Comello and Reichelstein (2014)
  – Extensions and enhancements (Massol, et al., 2015)
    • Increased costs due to potential reduced deployment in EU
    • Increased incentive costs need to ensure unique Nash Equilibrium

• Why do we create pre-announced tax incentives?
  – We want to incentivize early adoption before mandate
  – To do so at a minimum cost while not incentivizing a delay in implementation
Background

- In 2013, the U.S. Environmental Protection Agency (EPA) promulgated a new standard of CO$_2$ emissions
  - 500 kg per MWh
  - While lower than traditional coal-fired power plants, this standard is higher than what natural gas combined cycle (NGCC) typically emit (360 kg per MWh)
- Comello and Reichelstein (2014) propose a method and calculate the costs for limiting future fossil-fuel fired plants to 80 kg per MWh by 2027
  - About 80% capture for NGCC plants
  - About 90% capture for coal-fired power plants
- Two potential options for new facilities:
  - Adopt carbon capture capabilities at the outset
  - Start with a “conventional” facility that will then require retro-fitting in 2027 so as to comply with the EPA standard just in time

Bridging the Gap for Early Investment Costs

- Why should we create incentives for early adoption?
  - Most obviously, to reduce emissions by the newly built power plants
  - Perhaps more importantly, consistent adoption of the carbon capture technology (as noted in first part of the lecture) would ensure that the incremental costs would be reduced by 2027
- How do we create incentives for early adoption?
  - By making the Levelized Cost of Electricity (LCOE) favorable for early adoption for the post-2017 plants
- How do we calculate the LCOE?
  - where:
    - $LCOE$ = levelized cost of capacity per kWh based on useful life and cost of capital
    - $\delta$ = scalar for tax factor
    - $w$ = time-averaged variable operating cost
    - $f$ = time-averaged fixed costs
  - So, new plants must have an LCOE sufficiently small to incentivize early adoption vs. retro-fitting
Calculating LCOE under Different Alternatives

- Comello and Reichelstein (2014) use publicly available data from the National Energy Technical Laboratory (NETL) from the U.S. Department of Energy along with engineering estimates for the costs of NGCC with carbon capture
  - LCOE for a conventional NGCC facility commencing operations in 2017 is 6.6¢ per kWh
  - LCOE for an NGCC with carbon capture of 80 kg per MWh is 9.3¢ per kWh
    - Note that this 2.7¢ per kWh increase applies to first-of-a-kind facilities
- How does a public agency bridge the gap to incentivize earlier adoption and reduce overall learning curves?
  - Could fund projects to develop the technology (a la the real options model presented in Part I)
  - Could provide a series of tax investment and production credits to new power plants

Calculating the Optimal Firm Strategy 2017-2027

- First, what is the reduced cost due to learning?
  - If all newly built (post-2017) NGCC plants consistently adopt carbon capture technology, a new facility that becomes operational at the end of 2027 (and therefore, limiting its CO₂ emissions to 80 kg/MWh) has an LCOE of approximately 7.8¢ per kWh
  - For a conventional NGCC facility built in 2017 and is retrofitted to limit CO₂ emissions to 80 kg/MWh in 2027, its LCOE is only 7.2¢ per kWh, assuming all other plants consistently adopt carbon capture technology

![Graph showing LCOE over time with different strategies and emissions targets.](image)
Calculating Optimal Tax Incentives

• So, for any single plant, it pays to delay adoption (except in the final year), which will defeat the early capture and savings from learning. How do we ensure carbon capture adoption?
  – Recall that the LCOE will not be 7.8¢ per kWh in 2027 without consistent adoption
• Comello and Reichelstein propose a series of “Accelerated Carbon Capture Deployment” (ACCD) tax credits to bridge this gap:
  – For 2017-2025, all capital expenditures will receive Investment Tax Credits (ITC) of:
    • 23% for capital expenditures in 2017-2019
    • 13% for capital expenditures in 2020-2023
    • 8.7% in 2024; 4.3% in 2025
  – For 2017-2027 all facilities meeting emissions target will receive Production Tax Credits of:
    • 1.8¢ per kWh for 2017-2018
    • 1.1¢ per kWh for 2019-2022
    • 0.9¢, 0.7¢, 0.5¢, 0.3¢ and 0.1¢ per kWh for 2023-2027
  – Projected expenditures to the U.S. Treasury would be $6.6 billion

Analyzing the Proposed Tax Incentives

• Their innovative policy has several advantages
  – Cushions cost overruns for first-of-a-kind carbon capture
  – Provides a preannounced schedule
  – Appears to de-incentivize delaying CC adoption by making firms indifferent to between early adoption and 2026 retrofit
  – Reduces first-of-a-kind learning costs
  – Appears to optimize lost revenue to the Treasury
  – They provide an on-line copy of the (Excel-based) model
• However, several questions remain:
  1. How would inflation (not assumed in Comello and Reichelstein) affect the costs and deployment decisions?
  2. How do the assumptions about international (e.g., EU) deployments affect the projected LCOE and corresponding proposed tax credits?
  3. Can we be certain this incentive scheme is sufficient for adoption? If not, what are the additional costs needed to the tax schedule to ensure a non-divergence from adoption?
    • In Massol, et al. (2015), we address questions 2 and 3 above
Creating a Robust Tax-Schedule to CC Deployments outside the U.S.

- The LCOE calculations by Comello and Reichelstein assumes the installation of nearly 3 GW of foreign CC capabilities from 2014 through 2020
  - These are based on the Global Climate CCS Institute’s list of proposed projects
  - However, the funding of large CC projects in Europe has recently proven to be difficult, causing delays and some project cancellations
- To render the proposal robust to these potential delays and cancellations, we employ the NGCC-CC model developed by Comello and Reichelstein to calculate the needed ITC and PTC schedules
  - We assume non-U.S. deployments are restricted to the unique 2013 130MW power plant in Canada (used for enhanced oil recovery)

Creating a Robust Tax-Schedule to CC Deployments outside the U.S.: Results (1)

Modified ITC Schedule  Modified PTC Schedule

Summary of Robust Scenario Results

• The LCOE for 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
  – This is an increase, but the magnitude of the tax-credit levels remains likely politically acceptable
• Overall, the cumulated (undiscounted) foregone tax revenue to the U.S. Treasury reaches about $8.2 billion (from $6.6 in the base scenario)
  – This 25% increase over the base-case scenario reveals the positive externality provided by foreign early investments in first-of-a-kind CC plants
  – This robust schedule represents a cost-effective solution for achieving a large scale deployment of this innovative technology
What is the Subsidy Scheme?

• Let’s provide some detail about calculating these subsidies…
• First, we introduce some notation:
  – Consider a year $t \in \{2017, ..., 2027\}$
  – Let $K_t$ denote the total planned capacity of all power plants installed in year $t$
  – Let $CK_t$ denote the state variable that gives the cumulative capacity in the preceding years
  – $c^b_t$ is the cost of a last-minute retrofit at the end of 2027
  – $c^N(x)$ is a (decreasing) cost function of immediately adopting CC given the installed CC in operation at the time, $x$
  – We define the subsidized LCOE as $\tilde{c}^N_t(x) := c^N(x) - S_t$, where $S_t$ is the levelized subsidy at $t$

How Does the Subsidy Scheme Work?

• The Comello and Reichelstein model assumes the maximum level of CC adoption: $CK_{t+1} = CK_t + K_t$
• So the tax credits are calibrated such that $S_t \geq S^\ast_t$, where $S^\ast_t := c^N_t(CK_t + K_t) - c^b_t$
• These tax credits should prevent a possible deviation from an “equilibrium path”
  – If one models CC adoption as a one-shot game involving 11 players (one for each year) where each player faces a binary choice with respect to early CC adoption, the proposed subsidy makes “early adoption” the best response of every player when the other players also jointly decide “early adoption”
  – The proposed schedule of tax-credits makes the decision vector stating “early adoption” for every player a pure strategy Nash Equilibrium (NE)
Is the Subsidy Robust Enough?

• The potential problem with such a subsidy scheme is that it ignores the sequential, annual decisions and those impacts on CC capacity
  – Strategic interactions among the independent companies could occur
• Imagine a simple two-player game each with plant \( \frac{K}{2} \) of capacity. Assuming CC adoption has been decided upon by all previous players (thus \( CK_i = CK_{2017} + \sum_{t=2017}^{t-1} K_t \)), the unsubsidized game which each player is minimizing his cost would be:

<table>
<thead>
<tr>
<th>Player 1</th>
<th>Late adoption</th>
<th>Early adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( c_i^L ) ; ( c_i^E )</td>
<td>( c_i^L ; c_i^E \left( CK_i + \frac{K}{2} \right) )</td>
</tr>
</tbody>
</table>
|          | \( c_i^L \left( CK_i + \frac{K}{2} \right) ; c_i^E \) | \( c_i^E \left( CK_i + K \right) ; c_i^E \left( CK_i + K \right) \)

• Without a subsidy \( c_i^L < c_i^E \left( CK_i + K \right) \), and thus “late adoption” for both players is a unique NE

Is the Subsidy Robust Enough?

• With tax credit subsidy \( S \) as proposed, “early adoption” for each player is a NE (so far, so good…)
  – Proof can be found in the appendix of Massol, et al. (2015)
• However, it is a unique NE?
  – No, as “late adoption” for both players remains a NE for \( S_i = \bar{S} \). Why?
  – What is the required subsidy for Player 2 to choose “early adoption” when Player 1 chooses “late adoption”?
    \( c_i^L \left( CK_i + \frac{K}{2} \right) < c_i^E \)
  – Thus, we need a subsidy \( S_i \geq \bar{S} \), where \( \bar{S_i} := c_i^E \left( CK_i + \frac{K}{2} \right) - c_i^E \)
• However, \( S_i > \bar{S} \) as \( c_i^L \left( CK_i + \frac{K}{2} \right) > c_i^E \left( CK_i + K \right) \) since it is a strictly decreasing function
• We thus have:
  – Without subsidies, there is a unique NE (delay)
  – Implementing the subsidy in Comello and Reichelstein could yield a coordination game with a second NE
  – To obtain a unique NE of early adoption, an increased subsidy is needed
Later Subsides Could Be Insufficient?

• With lower-than-expected CC adoption at $t$, the proposed subsidies in future years may be insufficient.
• If there is delayed adoption by some player(s) at year $t$, then the levelized subsidy in the next year could be insufficient since there is some $k_t < K_t$ of adoption and $c^N_t$ is strictly decreasing.
  – Thus, a subsidy that does not guarantee a unique equilibrium at time $t$ could make subsequent “early adoption” decisions suboptimal, leading to a “snowball” effect.
• So, what tax credit subsidy could be sufficient?

A Sufficient Condition for Early CC Adoption

• It is presumably desirable to produce a schedule of tax subsidies that eliminates the possibility of a NE that is other than early adoption.
• As there are yearly variations in the number and size of plants, it may be preferable to opt for a subsidy level that is large enough to be independent of these considerations.
• Namely, for each year $t$, a subsidy $S_t \geq \hat{S}_t$ where $\hat{S}_t := c^N_t (C K_t) - c_t^N$ and $C K_t := C K_{2017} + \sum_{r=2017}^{t} K_r$ is sufficient to induce the installation of CC capacity $K_t$.
  – In other words, the subsidy must be at least equal to the difference in the retrofit costs and the adoption costs based on last year’s installed capacity—starting from $t=1$ (i.e., 2017).
• How does this change the costs?
Tax Credit Schedule Necessary for Unique NE (1)

- These increased subsidies guarantee
  - a unique NE
  - one that is robust to non-adoption in the EU (previously discussed)

Note that the ITC is relatively unchanged from the robust scenario, but the PTC values are considerably increased


Tax Credit Schedule Necessary for Unique NE (2)

Modified Schedule of Foregone Government Expenditures

- The modified subsidy (in foregone revenue to the U.S. Treasury) is $14.1 billion—a 110% increase over the value obtained in Comello and Reichelstein

Conclusions

• Comello and Reichelstein (2014) provide a nice approach for incentivizing early adoption of CC technology using publically available data and based on engineering estimates
  – Their ACCD calculator is available on-line
• Our work (Massol, et al. [2015]) considers two issues
  – What are the effects of (delayed) CC deployments outside the U.S.?
  – The “Accelerated Carbon Capture Deployment” (ACCD) tax credits may be insufficient to engender generalized early adoption of CC due to potential existence of multiple NE
• Though higher incentive levels are needed, our findings confirm that the cost of the proposed ACCD policy to the U.S. Treasury is not out of reach
  – This modified policy could represent an instrument to break the “vicious circle” that currently hampers the deployment of CC technologies

Thank you
References

• Main References:

• Additional References: