# *OPTIMAL TIMING OF PHASING OUT PRODUCER SUBSIDIES UNDER ENVIRONMENTAL UNCERTAINTY*

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## Overview

Since subsidies for fossil-fuel producers entail “carbon locked-in” risks, phasing out the subsidies is widely agreed to be critical for progress on climate change and low-carbon action. However, due to the uncertainties and irreversibilities associated with environmental degradation and economic losses, whether the removal action should be taken currently or be delayed into the future becomes vital for policy making. We develop a real option model of policy timing using the standard Hotelling model of resource exploitation, and a stochastic state variable to capture uncertainties over the social costs of environmental damage. Analytic solutions are derived to show the implication of these uncertainties for the timing of policy adoption; finally, we present a quantitative illustration and obtain the following results: (i) the percentage volatility of economic costs per emissions has a large positive incentive for waiting rather than adopting the policy at present; (ii) the percentage shift of economic costs per emission, pollution stocks, producer subsidies, declining production and marginal costs of fossil fuels have negative impacts on timing, which implies that adopting currently is better than waiting; and (iii) the discount rate has a positive impact on timing when it is larger than the percentage shift, and vice versa.

## Methods

Since the subsidies exert their influence on producers, whether or not the subsidy policies can realize the government target largely depends on the behavior of producers. A green social welfare is chosen as the target, which includes producers’ benefits and the losses of environmental pollution. Our model describes producers’ benefits from fossil energy exploitation using the standard Hotelling model, a self-regenerating pollution stock, and a stochastic state variable to capture uncertainty over the social costs of environmental damage. The producer must choose the optimal extraction path achieving the maximum discounted profits. In this instance, we assume a positive constant discount rate denoted by *r*. The social planner problem consists of determining the path {Qt, t⩾ 0} that maximizes social welfare:

$$W_t = \int_0^{\infty} \left[ P_t \cdot Q_t - C(Q_t) - B(M_t, \theta_t) \right] e^{-rt} dt$$

Let M(t) be a state variable representing the average level of the atmospheric carbon concentration at time t, and let E(t) be the flow variable denoting the rate of $CO_2$ emissions, which is a function of the consumption rate of fossil fuel. We assume that the pollution stock is self-regenerating at constant and positive proportional rate δ,

$$\frac{\mathrm{d}M}{\mathrm{d}t} = \beta E(t) - \delta M(t)$$

Furthermore, the quadratic B in M is used to describe the economic damage (Pindyck, 2002):

$$B(M_t, \theta_t) = -\theta_t \cdot M_t^2$$

We use Bellman equation to solve the dynamic programming problem:

$$rW = PQ - C(Q) - \theta M^2 + (\beta Q - \delta M) W_M + \alpha \theta W_\theta + \frac{1}{2} \sigma^2 \theta^2 W_{\theta\theta}$$

The optimal analytic solutions are obtained by the value-matching and smooth pasting conditions.

## Results

we perform a comparative static analysis to determine how environmental uncertainties influence the optimal timing of policy adoption. The case of percentage shift α=0.01 corresponds to the assumption made in Pindyck

(2002). The discount rate is set as r=0.04 (Pindyck, 2002). The absorption parameter is $\beta=0.58$ (oil) (IPCC 2006), and the average production of fossil fuel is Q=5 million barrels (annual production). The subsidies for producers are 1 million dollars. Next, we set the initial value of volatility parameters, the percentage volatility $\sigma$, $\sigma=0.2$ (Pindyck, 2002). This value implies an annual standard deviation of 20% for the social cost generated by the pollutant stock; the change proportion of production with or without subsidies, $\mu=0.1$ (Erickson, 2017); the marginal cost is 30 dollars per barrel, including finding and lifting costs per BOE (barrel of oil equivalent) (U.S. EIA, 2011).

The percentage volatility $\sigma$ has large positive effects on the optimal policy threshold $\theta^*$, which means a greater incentive for waiting rather than adopting now. Additionally, pollution stocks M, in combination with subsidies S, their influence proportion $\mu$, and marginal costs MC, have slightly negative impacts on the threshold. The results mean that adopting the policy rather than postponing it along with increases of these parameters. Finally, production Q and percentage shift $\alpha$ have large negative impacts. These results also imply that the optimal policy threshold is more sensitive to changes in the percentage volatility.

## Conclusions

In this article, a model for policy timing of phasing out producer subsidies of fossil fuel is developed, in which the government can optimally choose the policy timing. The government faces uncertainties about the economic costs of environmental pollution stock, which follows a geometric Brownian motion. This timing problem is explored through the use of continuous-time real option model in which adoption could occur at any time, and there is uncertainty over the future economic benefits of policy adoption, and over the future evolution of the pollutant stock. The real options framework is used, which allows the government to wait for more information before making a policy decision. The article reveals the following results:

- A higher percentage volatility of economic costs per emissions leads to a higher optimal policy threshold, which implies stronger incentives for waiting than for adopting the policy now.
- The combination of the subsidy amount and their influence proportion on production has slightly negative effects on the optimal threshold, reflecting an incentive to adopt now than wait.
- The discount rate has a two-stage influence on the optimal value of policy timing. When the discount rate is less than the percentage shift, the value of discount rate r is closer to the percentage shift; thus, a lower threshold $\theta^*$ will be the result. When the discount rate is larger than the percentage shift, an increase in the discount rate leads to a higher policy threshold which implies an incentive to wait rather than execute now.
- Whether in a field or a nation, the production of fossil energy will inevitably deplete. The decline of production leads to an increase of the optimal threshold. We can derive that the depletion of production exerts an incentive to wait rather than adopt the policy now.
- The marginal costs of fossil fuels are increasing as extraction proceeds. Increasing marginal costs result in a small decrease of the optimal threshold, which reveals a higher incentive to adopt the policy now rather than wait.

## References

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