[*ON THE DYNAMICS OF SUSTAINABLE ENERGY TRANSITION AND POLICY IMPLICATIONS: A PARTIAL EQUILIBRIUM APPROACH*]

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Overview

[The negative externality of global warming, the path dependence on carbon intensive fossil fuels, and the great challenge to sustainable economic growth call for an urgent low-carbon transition of existing energy system, which is equivalent to switching from a carbon intensive to a carbon free system. Recent economic research by general equilibrium model and microeconomic model emphasize the importance of sustainable energy transition in addressing climate change and promoting sustainable development and depict some certain properties of transition to clean technology.The detailed equilibrium dynamics of the transition path have not been fully characterized, however. For example, the shift of energy price due to mitigation policy and the possible consequence of capacity constraint on renewable energy are the main two concerns needing further quantitative research.This paper is an attempt in these directions.]

Methods

[The objective of this paper is to systematically analyze the equilibrium dynamics of sustainable energy transition within a partial equilibrium framework, where both the mitigation policy and capacity constraint on renewable energy are taken into consideration as necessary constraint factors. Besides, there are other three distinguishing features in the framework. First, the reserves of exhaustible fossil fuels are strictly positive when moving into the renewable energy era because the extraction costs increase without bound as fewer stocks are accessible. Second, the utility of an energy sector is determined simultaneouslyby the energy price and the quantity of energy service provided to consumer, and fossil fuels and renewables are perfect substitutes for producing energy services. Third, adjustment costs of capacity development of renewable energy are assumed to better conform to the reality.The main results and possible marginal contributions are summarized as follows.]

Results

[The first contribution is to illustrate the steady state after moving into the sustainable energy future, where renewables are the dominant energy sources and the accumulative capacity of renewables represented by $K(t)$ is the only state variable since then. The capacity will converge to the steady state along the saddle path from two different directions (Fig. 1 in the full paer). If the economy starts at a capacity lower than K^*, a slight increase of capacity will generate a marginal profit, and then the stock of renewables accumulate up to K^* with a declining optimal investment path because of the future energy price is a decreasing function of renewables capacity. On the contrary, if the economy starts at an excessive capacity higher than K^*, the stock of renewables will depreciate rapidly to K^* with a positive investment. At the steady state, the energy industry has no incentives to increase or decrease its supply of energy service.

The second contribution is to characterize the temporal dynamics of energy price and renewables investment during the transition process. Assuming that the capacity is not in excessive state, we can get continuous equilibrium paths of energy price and investment (Fig 2 in the full paper). The equilibrium energy price, which is consistent with the renowned “Hotelling Rule”, consists of the marginal cost of exploiting fossil fuels, the scarcity rent (shadow price), and the social cost of carbon emissions during the transition, and it converges to the full costs of renewable energy production in the renewables-dominated era for $t \geqslant t_X$. Mitigation policy adopted by energy sector would depress the energy price leading to a more flat path for $t_m \leqslant t \leqslant t_X$, however. For the optimal investment (shadow price of accumulative capacity)in renewable energy, it is categorized into four phases including zero investment for $t \leqslant t_K$, capacity accumulation without service provision for $t_K \leqslant t \leqslant t_y$, capacity expansion with energy service from both fossil fuels and renewables for $t_y \leqslant t \leqslant t_X$, and asymptotical convergence to the steady state in infinite time.]

Conclusions

[The relevant policy implications abstract from the results above can be revealed. First, from an economic perspective, energy price is the main driver of sustainable energy transition, and the shape of optimal investment path is attributed to the changing energy price. The depressed energy price caused by mitigation policies may stimulate fossil fuel energy consumption in some other countries those don't adopt any mitigation measures and then result in carbon leakage, or it may promote resource extraction by the resource owners for property safety because the tightening climate policies would increase the property risk of fossil fuels in situ. Second, after moving into the sustainable energy era, the capacity constraint condition generates a steady state, and we deprive a declining energy price path which is distinctive from the feature of a green Ramsey model result. Third, the optimal Pigouvian carbon tax equaling the marginal social cost of carbon emissions can be imposed to generate a first-best outcome and to speed up the transition process. Besides, subsidizing renewable energy is another effective approach to accelerating the phase in of renewables in early stages. Nevertheless, subsidy has always been considered as a second-best policy instrument in neoclassical endogenous economic growth models without accounting for directed technical change in green technologies.

Caveat and limitation are that results and implications from our theoretical analysis need further empirical evidence for verification, and incorporating new socioeconomic data for numerical simulations on sustainable energy transition scenarios are necessary as well.]

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