Long-Term Endogenous Economic Growth and Transition Towards Renewable Energy

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Overview

The purpose of the present article is to build a bridge between the endogenous economic growth theory, the biophysical economics perspective, and the past and future transitions between renewable and nonrenewable energy forms that economies have had and will have to accomplish. We provide a theoretical endogenous economic growth model subject to the physical limits of the real world, meaning that nonrenewable and renewable energy production costs have functional forms that respect physical constraints, and that technological level is precisely defined as the efficiency of primary-to-useful exergy conversion. Our model is calibrated on historical global data (1750-2010) and is able to reproduce an increasing reliance on nonrenewable from an early almost-renewable-only regime and the subsequent inevitable complete transition towards renewable energy that human will have to deal with in a not-too-far future.

Methods

The economy under consideration has three competitive markets for: the final output good, capital and energy. The production of the final good is operated by a representative firm and requires capital and energy. This final output, representing the gross world production (GWP), is then allocated to consumption or investment by the representative household. The accumulated capital is detained by the household and rented to: the nonrenewable renewable energy sectors and the final good sector. Nonrenewable and renewable energy (hereafter NRE and RE respectively) are considered to be perfect substitutes and are consequently sold at the same price. A representative firm operates the NRE stock (aggregation of coal, oil, gas and uranium resources) with an increasing unitary cost of extraction that is however attenuated by technological progress. In the same way, another representative firm exploits a free primary RE flow (say radiant energy from the sun) considered to be constant and so large that its availability cannot constraint the economy. This RE flow is operated with a decreasing unitary cost of production and under decreasing returns to scale. Technological progress increases the energy productivity of the final good sector and also affects the capital intensiveness of both NRE and RE sectors so that energy-producing and energy-using sectors are ‘technologically consistent’. This technological progress evolves endogenously but it is formally bounded from above implying that the energy and capital requirements for industrial or energy production cannot be nil and tend asymptotically towards positive values.

Results

The main conclusion of this paper is clear: for an economy in which energy-producing and energy-consuming sectors are technologically consistent, and in the absence of any correction of the price system, the final efficiency of primary-to-useful exergy conversion of the economy must be sufficiently high (above 0.35) in order to have a smooth transition from nonrenewable to renewable energy that does not negatively impact economic growth. In our model the economy cannot avoid a temporary energy lock-in (unanticipated nonrenewable energy peak occurring at a low level of renewable energy production) when this requirement for future technological level is not attained. In such circumstances the energy transition from nonrenewable to renewable energy induces an overshoot and then degrowth of the economic product. Such lock-in behavior of the economic system can be (at least partially) avoided through the implementation of a carbon price, which has also the benefit of decreasing GHG emissions from fossil-fuel use and hence mitigating climate change. Therefore, implementing a carbon price on nonrenewable energy production and recycling its revenue could help in the choice of the best development path that, at minimum, should consist in a smooth energy transition that does not negatively impact economic development.

Conclusions

Our model supports the idea that both the quantity of net energy supplied by energy-producing sectors to the energy-dissipative economy, and the ability of the economy system to use this energy (in fact exergy) are key elements of economic growth. To our knowledge, we are the first to develop a simple theoretical model that can calibrated on global historical data and correctly reproduce long-term global historical trends for nonrenewable and renewable primary energy supply, aggregated technological progress, and GWP. This is mainly because, unlike similar approaches, we have ensured that our theoretical model respects some of the many fundamental biophysical limits of the real world. These are formalized in the functional forms that we have established for the capital requirements of nonrenewable and renewable energy productions, and in the aggregated technological progress definition taken as the efficiency of primary-to-useful exergy conversion.

However, in its current formulation our model cannot be used to define endogenously the optimal time path of the carbon price, nor the optimal time path allocation of the carbon tax revenue among the different recycling uses. This would require including the role of politic and economic institutions in order to explain how producers and consumers receive adequate incentives to change their behavior.