ANALYZING LONG-RUN WELFARE IMPLICATIONS OF GREEN POLICY IN A R&D DRIVEN GROWTH MODEL

Deniz E Boz, Colorado School of Mines, +1 7208429410, denizegeboz@mines.edu
Carol Dahl, Colorado School of Mines, 303-273-3921, cadahl@mines.edu
Jared Carbone, Colorado School of Mines, 303-384-2175, jcarbone@mines.edu

Overview

As destructive 100 year climate events increase in frequency and scientific evidence mounts, the need to reduce the carbon intensity of human activity is becoming increasingly clear. However, doing so is a challenge. For example, almost half of the annual energy investment in the U.S. as the biggest economy in the world is composed of the capital expenditures of the oil and gas industry, and an overwhelming majority of these investment are being made for increasing fossil fuel supply (IEA, 2021). Around 60% of total electricity production is also sourced from fossil fuels in the U.S. (EIA, 2021) and the majority of the U.S. economy is dependent on carbon intensive inputs and end-products. How to reduce this dependency and substantially bring down the carbon intensity is not so clear. It necessitates undertaking the challenging goal of transforming and innovating how energy is sourced to run the production processes and used to consume the final goods. Given that most humans value the present strictly more than the future, and most of the negative externalities are born outside the fossil fuel industries, it is likely that imperfect markets will over provide high carbon technologies and under provide low carbon technologies.

Both carbon intensive industries, energy markets, and R&D investments incorporate various forms of externalities that originate from the asymmetry between private and public benefits. Various industrial and environmental policy tools exist to address such externalities. However, the multi-faceted nature of the energy problem renders choosing the right tools and approach rather complex. Such choice demands detailed dynamic analyses within the entire economic system. Thus, we need a growth model with welfare as a function of both income and the environment. Conventional growth models typically have aggregate production as a function of capital, labor and technology and do not often include energy explicitly as an input. When carbon intensity of production has been considered, it has been treated as a property of differentiated capital input industries. This does not allow the investigation of distinct energy industries that supply the energy inputs to the rest of the economy and related policies surrounding their activities. Nor do they allow separate technical change in each of the energy industries.

We consider the central role of research and technological development in a top-down general equilibrium setting with an emphasis on the fact that energy is a fundamental input to every economic process. Thus, any intervention that structurally affects energy markets and cause changes in equilibrium prices and quantities will influence other industries to varying degrees. Our contribution is to not only add substitutable energy inputs into the aggregate production functions but also to endogenize low carbon and high carbon energy industries. Further, we add separate technical change to each industry (i.e. renewables and carbon capture and storage (CCS)). Thus, we can analyze the implications of policies on the output and profitability of these industries as well as the benefits and costs to welfare, growth and technological development in the U.S. macroeconomy.

Methods

In this paper, we develop a macroeconomic growth model by considering the social planner's problem. The intertemporal utility function of a representative household comprising consumption and environmental quality is maximized subject to respective constraints of capital accumulation and environmental degradation. We extend Romer's (1990) growth model by adding both low and high carbon energy markets explicitly while keeping the original R&D sector and his structure of monopolistically competitive technology enhanced capital sector. We also add environmental quality as an essential source of welfare and model competitive or monopolistically competitive energy producers. This will allow us to incorporate climate externalities caused by the dependence on fossil fuels and explicitly account for the dynamic behavior of differentiated energy producers and carbon saving technology production.

The explicit consideration of the dynamic market equilibrium conditions of fossil fuel and renewable energy markets within the economy is also an important extension to Acemoglu et al. (2012), which was one of the pioneering studies that built on Romer's model by including the environmental externalities embedded in innovation driven economic growth. They analyzed the dynamics of directed technical change between clean and dirty industries through human capital market size effects and price effects. Their analysis assumed that dirty and clean industries had the same R&D driven production functions with different greenhouse gas contents, which were used as inputs to final output. We do not distinguish between clean and dirty sectors for the intermediate capital technology producers (entrepreneurs) but rather employ a nested CES production function for all output producers in the economy that allows substitution between different energy inputs. Further, these energy inputs have to be purchased directly from energy producers in the economy who are endowed with natural resources rather than the final-output. Thus, the model can represent the distinct production processes of depletable dirty energy and renewable cleaner energy. Dirty energy is a function of finite reserves enhanced by exploration following Pindyck (1978). Renewable energy production will mimic the intermittent supply of wind energy. Furthermore, we allow the existence of a R&D driven supply sector of carbon capture and storage (CCS) technology by simply following Romer's knowledge accumulation function. This kind of modelling approach also diverges from the endogenous technology general equilibrium formulation ENTICE developed by Popp (2004) that was built on Nordhaus`s DICE model. While the ENTICE model has a much more detailed bottom-up representation of regional market dynamics of various energy intensive industrial goods and their respective markets, it only considers the role of R&D in improving energy efficiency. It does not allow for the substitution between clean and dirty energy in the production of technology intensive industrial goods. Nor does it explicitly model differentiated energy markets or deploy CCS technologies. Our main goal is to analyze various combined environmental and industrial policies that have tax neutral effect for the aggregate energy sector in the context of the U.S.

Results

Quantitative outputs of the model will be based on simulations for the U.S. for a 50-year time horizon with a variety of low carbon policies including Section 45Q tax credits for CCS, R&D subsidies, and pricing of CO2e emissions. When finished, this paper will provide equilibrium employment, relative production rates and market prices for the two differentiated energy producers, evolution of R&D investments, technology enhanced capital and GDP production under limited resource, environmental constraints, different energy market structures and tax revenue allocation schemes. Preliminary results suggest that pricing carbon at a sufficient rate and allocating revenues among fossil fuel producers and renewable energy producers can lead to significant increases in the deployment of CCS technologies. This can win enough time for renewable technologies' market share in the energy sector to catch up with fossil fuels without necessarily slowing down economic growth significantly. If our revenue neutral policies within the aggregate energy sector are politically infeasible, we will also consider levying a tax on consumption that matches the representative households` marginal utility gain from environmental quality. If we can legitimize this tax by convincingly communicate that the tax truly represents households' preferences, allocating the cost burden of carbon price among agents in the economy will also be considered a viable funding source of low carbon polices. This second-best option can only be legitimized if the intertemporal utility when carbon is not priced at all in the economy is less then when it is priced.

Conclusion

The main conclusion of the paper is that carbon emissions need to be sufficiently priced in the economy for any of the Paris Climate goals to be met to prevent devastating effects of climate change in the upcoming decades. Long-run welfare implications of specific and combined policy options will be revealed when the simulation experiments are completed as well as their effects on the outcomes of individual industries. How will the cost burden of cumulative greenhouse gases is shared between representative households and energy producers in a dynamic setting will economically be based on the relative marginal costs and benefits. Welfare costs will be quantified to represent the trade-off between political feasibility and long-run economic efficiency.

References

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