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A discrete choice model of transitions to sustainable technologies☆

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ABSTRACT

We propose a discrete choice model of sustainable transitions from dirty to clean technologies. Agents can adopt one technology or the other, under the influence of social interactions and network externalities. Sustainable transitions are addressed as a multiple equilibria problem. A pollution tax can trigger a sudden transition as a bifurcation event, at the expenses of large policy efforts. Alternatively, periodic dynamics can arise. Technological progress introduced in the form of endogenous learning curves stands as a fundamental factor of sustainable transitions. For this to work, the positive feedback of network externalities and social interaction should be reduced initially, for instance by promoting niche markets of clean technologies and making technological standards and infrastructure more open. Traditional policy channels such as pollution tax and feed-in-tariffs have an auxiliary – yet important – role in our model. Compared to feed-in-tariffs, a pollution tax promotes smoother and faster transitions.

1. Introduction

Resource scarcity, climate change and environmental justice are among the major challenges faced by human mankind in present times. These challenges require profound changes of industrial and agricultural sectors, but also involve behaviours, institutions and more generally the organization of society. In particular environmental challenges call to reform energy, housing, and transportation, and pose new targets for technological progress towards sustainable solutions (van den Bergh, 2012).

There is currently little evidence that major changes occur in energy solutions, and in particular no evidence of relevant transitions towards sustainable power generation. Fig. 1 contains the time series of different sources of energy production in the United States. The data show little change from 1972 until 2008: the aggregate amount of fossil fuels (coal, oil and gas) maintains its leadership almost untouched, and renewable energy is not able to score any appreciable gain of market shares. All this suggests that the economy and the whole society are stuck into an equilibrium where fossil fuels are the dominant

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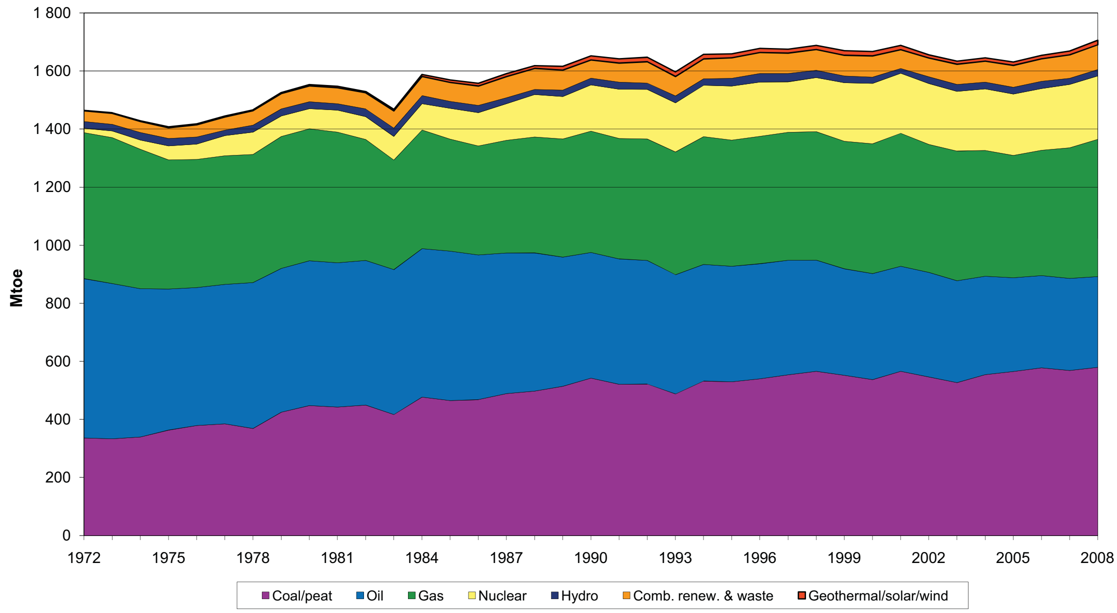

Fig. 1. Energy production in US: time series of different sources (source: OECD/IEA).

technology for energy production. Why this is so, despite substantial technological progress in renewable technologies, and environmental policy actions, at least in some developed countries? Power generation is just one, yet important, example of industrial sectors causing major damages to the environment and contributing to climate change. Other examples are transportation systems, which also heavily rely on fossil fuels.

Technology plays a primary role in the interplay between the economy and the natural environment, which is strongly relevant to a model of climate change mitigation. However, this role has been recognized only recently. In the economic literature, notable examples are models of endogenous growth theory, such as Acemoglu et al. (2012) and integrated assessment modeling, as Popp (2004), for instance. However these models pose little attention to the heterogeneity of economic agents and their decision process, neither to the dynamics of competition between multiple technological options. The study of these issues in the context of sustainable transitions is the starting point of our paper.

Sustainability concerns have become central in innovation studies and environmental economics, leading to the concept of "sustainability transitions" (Kemp, 1994; Köhler et al., 2009; Markard et al., 2012). A transition path of climate change mitigation is quite different from a gradual and linear path, with strong implications for macroeconomic theory and environmental policy (van der Ploeg, 2011). Moreover, the intrinsic dynamic nature of a transition event finds a natural conceptual framework in evolutionary modelling (Foxon, 2011).

Sustainability transitions often imply a regime shift from an established technology to an innovative technology. The idea of technological regime is central to transition thinking and to evolutionary economics (Nelson and Winter, 1982). A technological regime has often the connotation of "lock-in" (Arthur, 1989). A technological lock-in is a state in which one technology is dominant in a particular application domain or industrial sector, and competing alternatives find it hard if not impossible to enter the market, even if they are socially desirable (David, 1985).

Technological lock-in is the result of increasing returns to adoption: a technology tends to be more attractive the more it is adopted. Several factors give place to this positive externality in adoption decisions: learning effects among producers and users, the advantages of common standards and infrastructure, and the provision of complementary goods, services and institutions. These factors add to the utility of using a technology and in economics are often referred to as "network externalities" (Katz and Shapiro, 1985).

Network externalities give rise to barriers which are strong to be broken. This scenario translates into multiple equilibria, and once the economy is stuck in one of those, with one technology dominating the market (technological lock-in), it is hard for alternative technologies to gain market shares, let alone to overcome the dominant technology. In the energy sector, a shift from the equilibrium represented by fossil fuels is very hard to achieve, due to the large scale of infrastructures and amount of investments, a fact that suggested the notion of "carbon lock-in" (Unruh, 2000; Könnölä et al., 2006). A possible way to escape carbon lock-in has been analysed by Zeppini and van den Bergh (2011) with the concept of "recombinant innovation".

There are other sources of positive feedback, beside network externalities, which stem from social interactions in the form of imitation and social learning (Young, 2009), conformity effects and habit formation (Alessie and Kapteyn, 1991), or even forms of recruitment (Kirman, 1993). In this paper we propose an analytical framework for the study of sustainability transitions based on discrete choice dynamics, building on social interactions models such as Brock and Durlauf (2001).