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ANALYSIS

Energy, money, and pollution

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Abstract

This paper explores general equilibrium consumption choices and interest rate determination in a deterministic two-period model in which the production side explicitly describes the thermodynamic process unavoidably connected with production, as argued by Georgescu Roegen. A simple energy based production process is modeled, which is not in a stationary state. The resulting production function is time dependent. In neoclassical general equilibrium the thermodynamic implication of the production process, i.e., the production of waste, will not be taken into account by decision making agents. For welfare optimality, the resulting externality needs to be corrected by a social planner, or through the use of environmental related taxation. However, it is shown that imposing energy as a medium of exchange (money) in the same economy makes agents energy conscious and decreases the externality associated with entropic waste through a market mechanism, without the need for intervention. In the limit case in which production occurs in thermodynamic equilibrium, no entropic waste is produced, and the model collapses to the nested neoclassical model. A contribution of the proposed approach is the determination of energy (money) prices in general equilibrium. Despite the fact that energy does not enter the agents' utility function, and therefore has no direct value, money prices and interest rate can be fully characterized in the model due precisely to the production technology adopted. In this competitive equilibrium the market interest rate will be greater than the real interest rate. The change in the numeraire and medium of exchange used affects the economy due to the non stationarity of the production process, but has no effect in the limit case in which the productive process reaches a steady state.

Keywords: Market equilibrium; Second law efficiency; Entropic waste; Cash in advance; Nominal interest rate

1. Introduction

Among the key objections to the welfare optimality of competitive market equilibrium, the issue of externalities, which are not properly evaluated by individual decision making agents, is a critical one. Negative externalities impact general welfare beyond the immediate perception of the decision making individual. Since the work of Ayres and Kneese (1969), waste externalities and environmental pollution have acquired a central place among the negative externalities of the economic process. Environmental pollution can be broadly characterized as entropic waste, i.e., dispersion into the envi-

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ronment of low quality energy, creating environmental disorder without achieving any economically valuable goal (Kümmel, 1989).

Entropic pollution cannot generally be accounted for in a neoclassical general equilibrium model. In addition to the difficulties of highlighting the role of externalities in general, entropic pollution will not be present in such models where the formal structure of production theory is based on stationary production functions. The stationary neoclassical production function does not accommodate the role of time and the related concepts of entropy and waste. These issues have been accurately analyzed in the work of Georgescu-Roegen (1971), which provides the basis for a realistic general theory of production, including the concept of waste. Nevertheless, the neoclassical paradigm of production is often used in the analysis of the thermodynamic efficiency of production (Ruth, 1995; Stern, 1997).

In this paper, production activity is described by means of a simple production function which makes the underlying irreversible thermodynamic process completely apparent, as suggested by Roma (2000). The implications for the equilibrium of the economy and waste production are fully spelled out through a simple deterministic model.

The structure of the firm's problem in respect of the level of waste is very similar to the theory presented in Ethridge (1973). The firm jointly produces two products, one of which can in turn be split into an economically useful product and an undesirable output, waste. However, here we include time to produce and a thermodynamic constraint on production which fully specifies the technology. Moreover, in the approach presented a physical limit to aggregate production possibilities is introduced, and the technology does not allow input substitution.

With this description of the production side, entropic pollution becomes visible, and we are able to formally characterize the associated waste in a general equilibrium framework. Still, in the neoclassical model decision making agents will completely ignore it in their choices. Producers will set optimal production plans ignoring the consequences of waste, and the affected consumers will not be individually able to influence this decision. However, it is shown that a simple monetary arrangement, namely adopting energy as a numeraire and medium of exchange will lead decision making agents to modify their choices, compared to the pure barter economy solution, thus shifting the equilibrium towards a decrease of the amount of entropic waste. This choice of the numeraire is a natural way to make agents energy waste conscious and internalize the externality. The proposed mechanism provides an alternative to the usual approach to waste reduction through environmental related taxation. A contribution of the present approach is the determination of energy (money) prices in general equilibrium, which can be solved for due to the specific thermodynamic production process assumed. As a limiting case, if production indeed occurs in thermodynamic equilibrium (which would require infinite time), then entropic pollution is not produced (and need not be taken into account), and the resulting market equilibrium will revert to that of a neoclassical barter economy. The neoclassical competitive equilibrium model turns out to be a special case of the model proposed here. In this way, the model illustrates the connection between stationary and time dependent economic production, reconciling this approach with classical textbook microeconomics.

The plan of the paper is as follows: Section 2 describes the Georgescu Roegen type production process and presents a simple thermodynamic characterization of technology. The production process takes place over a finite time interval and allows for output to be available at two different dates, with the unavoidable joint production of waste. In Section 3 the tradeoff between output (and consumption) at the two dates is embedded in a simple general equilibrium model, and the various possible ways to internalize the waste externality are discussed. A feature of the production technology is that it allows easy computation of the output energy price. We can adopt energy as the numeraire and medium of exchange of the economy and compute the resulting decentralized equilibrium. Section 4 provides a discussion of the modifications of the decentralized equilibrium, with respect to the neoclassical solution, brought about by the use of energy money. In particular, it is shown that the production of entropic waste will be smaller than in the corresponding neoclassical barter economy. Therefore, in the presence of waste externalities, market equilibrium under the energy numeraire may deliver the same optimal allocation which would