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Economic and environmental effects under resource scarcity and substitution between renewable and non-renewable resources

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HIGHLIGHTS

- Our general equilibrium model includes renewable and non-renewable resources.
- Under constant resource production costs emissions grow at the same rate as output.
- Resource producers can invest in knowledge to reduce production costs.
- Under decreasing costs, lower emissions are compatible with stable output growth.
- Empirical results differ under constant costs and under endogenous technical change.

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ABSTRACT

We build a general equilibrium model with renewable (non-polluting) and non-renewable (polluting) resources to analyze the interaction and compatibility between economic growth and a cleaner environment. The study is in two phases: (i) resource extraction/production costs are constant; (ii) resource producers invest in knowledge to reduce extraction/production costs, endogenizing technical change. With constant costs, there is a permanent trade-off between economic growth and a cleaner environment. With endogenous technical change, it is possible to harmonize more output and less emissions by replacing non-renewable resources for renewable ones. We also conduct a sensitivity analysis to explore three specific policy actions. With constant costs, the best policy action is the imposition of a higher renewable resources standard, while with endogenous technical change, under certain conditions, all policy interventions may benefit both the economy and the environment.

1. Introduction

In this paper, we investigate the connection and compatibility between economic growth and a cleaner environment. In particular, we perform this investigation in a framework where exhaustible (polluting) resources are replaceable by renewable (non-polluting) ones. This analysis requires the joint consideration of three building blocks: the relationship between economic growth and resource exhaustion; the relationship between resource consumption and polluting emissions; the possible substitution between (non-polluting) renewable resources and non-renewable (polluting) ones.

The compatibility between economic growth and natural resource exhaustion has often been studied in the natural resources' literature, especially since the seminal works of Hotelling (1931), Stiglitz (1974), Solow (1974), and Dasgupta and Heal (1974). Barbier (1999), among others, showed that innovation allowed overcoming resource scarcity, while maintaining *per capita* long-run consumption levels. Grimaud and Rougé (2003) showed that, under certain conditions, technical change (TC) relaxed the constraints imposed by resource exhaustion. Similarly, Scholz and Ziemes (1999) showed that, in a context of imperfect competition, *per capita* consumption could grow if the market entry rate exceeded the average monopolist's decline in output. In general, the literature shows that, with endogenous TC, resource exhaustion does not necessarily harm economic growth. Our results also emphasize this importance of endogenous TC to reconcile the economy with the environment.

The second building block includes an additional feature: resource consumption often generates pollution. Some authors, within the natural resource literature, ignore this aspect (e.g., Grimaud and Rougé, 2003; Barbier, 1999; Scholz and Ziemes, 1999; Garg and Sweeney, 1978), while an equally large number of authors considered emissions (e.g., Grimaud and Rougé, 2005; Schou, 2000, 2002). Schou (2000, 2002) included non-renewable

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(polluting) resources and pointed out that if pollution results from resource consumption and resources are scarce, then the need to save them will unavoidably limit pollution. Notwithstanding, as stated above (Grimaud and Rougé, 2003; Scholz and Ziemes, 1999), and in line with our results, resource scarcity does not necessarily hamper economic growth, i.e., pollution problems may persist. Accordingly, if an economy uses polluting resources to produce, important questions arise in an era in which environmental aspects are central to the policy agenda. Under ecological restrictions, the need to consume less polluting resources may affect economic growth.

The possibility of replacing polluting resources by non-polluting ones may change this, which leads to our third building block. Through resource replacement, production may increase without further emissions. In spite of the growing importance of renewable resources over the past decades, only a relatively small fraction of the resource literature considers them. We describe some exceptions. Bovenberg and Smulders (1995) included environmental quality (natural capital) as a renewable resource used for production. This resource quality depreciated through pollution, but had a regenerative capacity. In their article, TC could reduce pollution and a constant environmental quality was feasible if natural capital consumption was replaced by man-made factors. Tahvonen (1997) extended the Hotelling model to include pollution and a backstop technology which showed that, typically, an optimal consumption strategy included both fossil and backstop sources. Nevertheless, through time, fossil-fuel consumption decreased and backstop consumption increased. Di Vita (2006) used a Cobb–Douglas production function including the technical substitution rate between resources. The author tested a rate equal to one and different than one and concluded that the economy performed worse when substitutability was imperfect. Hence, the literature suggests the importance of resource substitution.

The main contribution of our paper is that it provides a comprehensive analysis of the three building blocks, using a different framework. Most models use a Cobb–Douglas production function (e.g., Barbier, 1999; Di Vita, 2006; Stiglitz, 1974; Smith, 1974). While simplifying the calculations, this production function imposes an important limitation: the elasticity of substitution between inputs is unitary.[1] We consider a more general constant elasticity of substitution (CES) production function, which allows studying the effects of a higher elasticity of substitution between resources. Our analytical resolution shows that, in line with Di Vita (2006), only elasticity values higher than one are acceptable.

Our general equilibrium model is constructed in two phases. In the first phase, the base case (BC), extraction/production costs are constant for both types of resources. The assumption of constant costs is not too strong since many studies adopt costless extraction (e.g., Aarrestad, 1990; Agnani et al., 2005; Andre and Cerda, 2006). In the second phase, the endogenous technical change case (ETCC), resource producers invest in knowledge to decrease extraction/production costs. Additionally, we conduct a sensitivity analysis to three possible government interventions: a higher tax on emissions, a higher renewable resources standard and a higher elasticity of substitution between resources.

[1] This elasticity represents the ease of replacing one input for the other. If it is unitary, in order to decrease one unit of a given input and maintain the output, we have to increase exactly one unit of the other input. An elasticity lower than one means that it is harder to replace one input by the other (in the extreme case of a zero elasticity, inputs would be complementary instead of substitutable), while a higher elasticity, in particular higher than one, means that it is easier to replace inputs.

We follow Tahvonen and Salo (2001), but we introduce several changes. Firstly, we abstract from capital accumulation and the labor market since we are only interested in the dynamics between renewable and non-renewable resources. Secondly, we propose a model application with a functional form, the general CES. Thirdly, we include pollution. Finally, we diverge from Tahvonen and Salo (2001) in our purpose. These authors analyzed the transitional dynamics between renewable and non-renewable energy sources. In turn, we are interested in long-run equilibrium features when both sources are used.

Our main findings are that, in the BC, there is a permanent trade-off between economic growth and a cleaner environment. To produce more, the economy necessarily uses more non-renewable resources. Simultaneously, output and emissions grow at the same rate. On the other hand, in the ETCC, it is possible to have more output and less emissions if the economy replaces non-renewable resources for renewable ones. Government intervention is required for the necessary investments in the renewable resources knowledge stock as well as disinvestments in the non-renewable resources knowledge stock. The sensitivity analysis shows that, when costs are constant, only a higher renewable resources standard is beneficial both for the economy and the environment. A higher tax decreases output and a higher elasticity of substitution increases future emissions. When TC is endogenous, under certain conditions, all policy interventions may benefit the economy and the environment.

This paper is organized as follows. Section 2 presents the base model as well as the extended version and the equilibrium conditions in each case. Section 3 performs a sensitivity analysis to the tax level, the renewable resources share and the elasticity of substitution between resources. Finally, Section 4 presents some conclusions and policy implications.

2. The base model

Building on Tahvonen and Salo (2001), we consider a model in continuous time with three sectors: homogenous final-good, renewable resources (RR) and non-renewable resources (NRR). Final-good is used for consumption, for resources extraction/production and, in the ETCC, for knowledge investment.

Firstly, we present the BC, with fixed extraction/production costs and, in the ETCC, we include technical evolution in the resources sectors to decrease extraction/production costs. Over the years, the energy sector has undergone technical evolutions, making energy generation cheaper. For the renewable sector, these costs may include building wind parks or dams or even electricity generation costs. We do not focus on extractable resources like biomass.

2.1. General description

2.1.1. Final-good sector

There are N ($n=1,\ldots,N$) final-good producers facing perfect competition. Each firm has the following production function:

$$Y(n,t)=[\alpha R(n,t)^{(\varepsilon-1)/\varepsilon}+(1-\alpha)F(n,t)^{(\varepsilon-1)/\varepsilon}]^{\varepsilon/(\varepsilon-1)} \tag{1}$$

where Y is final output; R and F are, respectively, the amounts of RR and NRR consumed in each period; α is the RR share; and ε is the elasticity of substitution between resources which, theoretically, can assume values between 0 and $+\infty$. Resources are substitutes when $\varepsilon>1$ and complements when $\varepsilon<1$. This production function is similar to the one in van der Zwaan et al. (2002), but, for simplicity, we abstract from capital accumulation and the labor market.