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Introduction

Challenges for a sustainable resource use: Uncertainty, trade, and climate policies

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ABSTRACT

We integrate new challenges to thinking about resource markets and sustainable resource use policies in a general framework. The challenges, emerging from six papers that JEEM publishes in a special issue, are (i) demand uncertainty and stockpiling, (ii) international trade and resource dependence, (iii) deforestation, and (iv) intertemporal effects of climate change policies ("Green Paradox"). We discuss new insights and results on these issues by fitting them into the Hotelling model of non-renewable resource depletion.

1. Introduction

The sustainability of long-run development is threatened by a rapid extraction of natural resources. Current generations use the natural environment so intensively that the welfare of future generations may substantially be harmed. The use of the natural environment includes not only the reduction of resource stocks, like fossil fuels and rain forests, but also the accumulation of pollution stocks, as in the case of the climate problem. Measures and policies aiming at changing the resource extraction and pollution profiles have to rely on a sound understanding of the forces driving resource markets and their impacts on the aggregate economy.

There is a broad literature on basic resource extraction dating back to the seminal contribution of Hotelling [12]. The well-established fundamental mechanism of intertemporal arbitrage in natural resource markets is still contemporary for theory and policy. The specificities of natural resource supply make it indispensable for policy makers to think about the long-run consequences of their decisions and about market forces possibly counteracting policies because of intertemporal arbitrage opportunities. In this regard, the interest rate is a crucial parameter, as it not only affects the speed of resource extraction but also the investment decisions in the rest of the economy, which also have long-run economic consequences.

A series of additional issues are equally important to understand the determinants of resource extraction, most prominently (i) uncertainty about known stocks and demand, (ii) resource extraction cost, (iii) international trade relations, (iv) energy, pollution, and technology policy instruments like taxes and subsidies, and (v) alternative technologies serving as the so-called backstop resources, e.g. solar, that have the potential to fully replacing original natural resources like oil. Because intertemporal arbitrage is at the heart of the resource market mechanism, the expected and anticipated developments in future demand, cost, policy, and technology are as important as their actual current levels. Only a thorough and nuanced analysis of the myriad of interactions between determinants across space and time can establish the base for the design of sound policies that aim at increasing welfare and improving intergenerational justice.

We survey six papers, all initially presented at the 2010 Monte Verita Conference on Sustainable Resource Use and Economic Dynamics (SURED), that contribute to such an analysis. Our aim is to show how these papers build on and advance the insights from classical resource economics in the spirit of Hotelling [12]. We present the key insights and mechanisms from the papers and show how they employ common economic principles. To this end, we simplify – where

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useful – the original models and relate them to the basic Hotelling framework, which we introduce in the following section.

2. A Hotelling framework

The Hotelling framework that we use as the benchmark model in our discussions is standard. The first building block of the model is the resource owners' problem of maximizing net present value of profits from extracting and selling a given non-renewable resource stock. With p denoting the resource price, ζ the per-unit extraction cost, q the extracted quantity, S the resource stock, r the interest rate, and t the time index, it is represented by

$$\max_{\{q(t)\}} \int_0^\infty [p(t)-\zeta(t)]q(t)\exp(-rt)\,dt, \tag{1}$$

$$\dot{S}(t) = -q(t),\ S(0) = S_0 \text{ given}; \quad S(t) \geq 0. \tag{2}$$

The second building block represents the market equilibrium. Assuming a single representative resource owner, aggregate supply at time t equals $q(t)$. Aggregate demand for extracted resources is captured by a downward sloping demand curve, $D(p)$, with $D' \leq 0$, and market equilibrium requires

$$q(t) = D(p(t)). \tag{3}$$

A competitive equilibrium is a situation in which (i) resource owners maximize profits subject to the resource constraint and taking prices as given, and (ii) total supply equals demand. As is well known, under mild restrictions on the demand and cost functions,[1] the equilibrium rent $p-\zeta$ grows at rate r, i.e. the Hotelling rule applies.

The various models that we present and integrate below generalize the above model in various directions. To start with, the extraction problem can be generalized for economies of scale by assuming unit extraction costs are a function of the extraction rate, $\zeta(t) = c(q(t))/q(t)$ (Section 3); alternatively, extraction costs increase with depletion, which is modeled by assuming $\zeta(t) = m(S(t))$ with $m' < 0$ (Section 6). Furthermore, the cost of extraction might include a resource tax, which possibly reflects the social damages from depleting the resource and accumulating emissions in the atmosphere.

Taxes and subsidies generally affect resource extraction; they can be justified from a welfare-maximizing perspective in the presence of externalities. When private and social costs differ, the competitive equilibrium defined above would deviate from the first-best optimum. The centralized optimum maximizes the net present value of producer and consumer surplus, which in general is a function of the extraction flow $q(t)$ and stock $S(t)$, say $F(q(t),S(t))$. Maximization of

$$\int_0^\infty F(q(t),S(t))\exp(-rt)\,dt \tag{4}$$

with respect to $q(t)$ and subject to the stock constraint (2) yields

$$F_S + \dot{F}_q = rF_q, \tag{5}$$

where the subscripts denote partial derivatives. This well-known arbitrage condition equates the marginal benefits of a larger stock of resources (including both instantaneous benefits F_S and future benefits $\dot{F}_q$) to the marginal cost of resource conservation (which is the value of foregone extraction of resources, F_q annualized by r).

As a further generalization, we will introduce the production of an alternative to non-renewable resources for users, according to a backstop technology that does not require non-renewable resources. Substitutes to non-renewables are relevant in many different context, e.g. solar and biofuels in the context of energy supply and climate change. When resource users can satisfy their demand not only by buying extracted resources q, but also by buying the backstop resource, say b, we need to modify (3) into $q = \tilde{D}(p) - b$, where the right-hand side is residual demand for the non-renewable resource. We also need to specify how much of the backstop is supplied. In Section 6 we discuss three alternative assumptions: (i) perfectly elastic supply (at a cost β), (ii) imperfectly elastic supply (according to an increasing supply curve $B(p)$), and (iii) perfectly inelastic short-run supply with investments in capacity.

If a backstop technology or a renewable resource is not available as a substitute for non-renewable resource users, an alternative route to reduce the need for non-renewable resources in the economy is to invest in resource-efficiency. In particular, the accumulation of man-made resources that allow for the increased productivity derived from non-renewable resources would modify (3) into $K_q q = D(p)$, where K_q is resource-productivity and $K_q q$ is effective resource supply. It needs to be determined within the model how much is invested in raising resource efficiency K_q. This is where resource theory meets modern growth theory, in which investment, innovation and technical change are endogenous. Extended along these lines, the model can explain how the economy is able to increase resource productivity K_q endogenously, so that $K_q q$ can be constant or increasing despite of depletion of the resource stock.

In addition to the emergence of alternative energy sources, various other factors might affect resource demand. In reality, demand is usually uncertain, i.e. subject to shocks. Moreover, in a market economy demand comes from different sectors so that structural change has an impact on resource use. At an international level, demand for natural resources

[1] The different restrictions will become evident in the following sections.