Price Formation Of Exhaustible Resources: An Experimental Investigation of the Hotelling Rule

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Overview

Although Germany has an ambitious energy strategy with the aim of a low carbon economy, around 87% of the primary energy consumption was based on the fossil energies oil, coal, gas and uranium in 2012, which all belong to the category of exhaustible resources (BMWi 2013). Harold Hotelling described in 1931 the economic theory of exhaustible resources (Hotelling 1931). The Hotelling rule states that the prices of exhaustible resources - more specifically the scarcity rent - will rise at the rate of interest, and consumption will decline over time. The equilibrium implies social optimality. However, empirical analysis shows that market prices of exhaustible resources rarely follow theoretical price paths. Nevertheless, Hotelling´s rule "continues to be a central feature of models of non-renewable resource markets" (Livernois 2009).
We believe that there are difficulties in the (traditional) empirical verification but this should not lead to the invalidity of the theory in general. Our research, by using experimental methods, shows that the Hotelling rule has its justification. Furthermore, we think that the logic according to the Hotelling rule is one influencing factor among others in the price formation of exhaustible resources, therefore deviations are possible in real markets.

Methods

There are two main problems within the traditional research methodology. First, a theory can only be verified if its assumptions are met adequately. In the complex, real world there are several factors influencing the prices and allocation of exhaustible resources markets. Consequently the assumptions of the model, such as a constant demand function or perfect future markets, are violated. Livernois (2009, p.37) states that only by controlling all relevant factors "do we have a credible chance of refuting or supporting the Hotelling rule", which is still an unsolved task. Second, the data availability is consistently interfering. The development of the scarcity rent is of primary interest for the analysis. Since market prices are aggregated values of several components, scarcity rent is usually unobservable and, instead, must be estimated. This data issue usually remains because vertically integrated companies rarely publish the required data.
By using the experimental method, we meet all obstacles mentioned above by designing an artificial laboratory world. In particular, we designed an experiment with a continuous double auction (CDA) to examine if the market can solve the challenging intertemporal allocation problem. 10 Buyers and 10 Sellers participate in a market and each one of them can submit a bid respectively an ask actively or passively until one of the ten periods is over. Each seller has a stock of 50 resources to sell during the auction under the assumption of an interest rate of 20%. The data regarding the "Basic-Treatment" is based on 10 markets whereby 100 students participated in 5 groups playing 2 markets successively.

Results

Since we know from the literature that intertemporal decisions are challenging and that the subjects are confronted with different optimal price-quantity combinations in each period, there are doubts if the theoretical framework would hold true in the laboratory. However, we find that, in accordance with the theory, the period-wise median transaction prices are in a monotonically increasing sequence. Figure 1 shows the experimental market data (crosses) and the calculated theoretical optimum (dashed line) for the scarcity rent and the quantities. Altogether one can observe a relatively strong attraction to the theoretical equilibrium.

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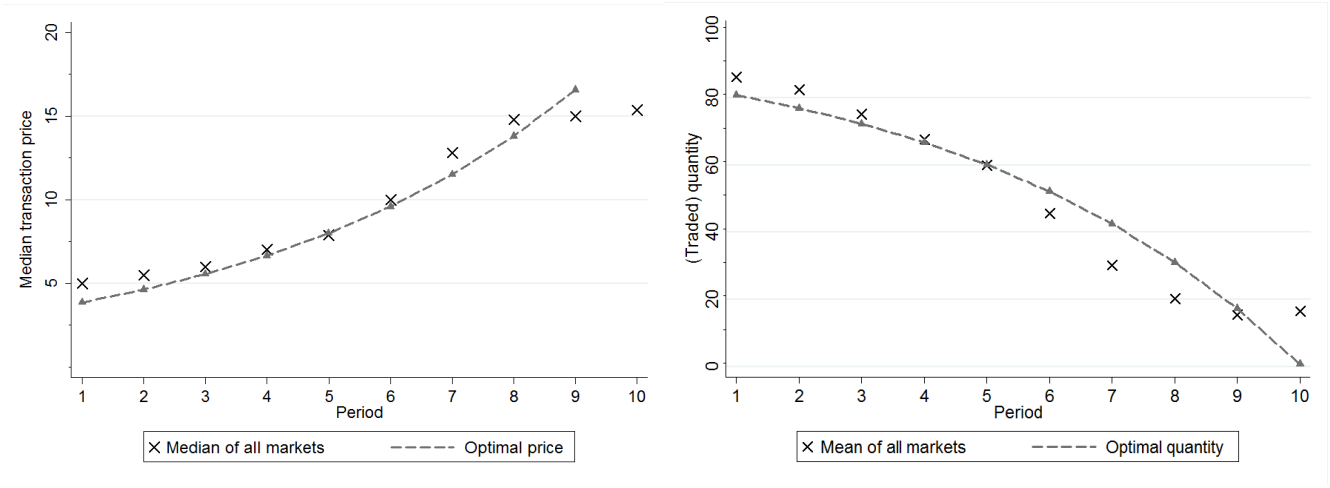

Figure 1: Prices (left): Scarcity rent of aggregated 10 markets of the Basic-Treatment. Quantities (right): Average trading volume of the ten sellers. Data is based on 10 conducted markets.

To quantify the observations we did also several nonlinear least-squares estimations. By considering the marginal prices[2], it is demonstrated that the data confirm the theory. Furthermore, there is evidence for learning effects: The second market with the same group achieves a higher market efficiency than the first market.
One fundamental question of the theory of exhaustible resources is whether one can expect that the market ensures an efficient intertemporal allocation of resources (Siebert 1970). Although this question is hard to answer in real markets, with experimental data it is relatively simple to perform this analysis. By dividing the producer and consumer surplus by the total possible surplus, a market efficiency of 97.95% is the average result. This high efficiency is in line with existing publications[3] and this result is reasoned for a large part in the design of the CDA.

Besides the Basic-Treatment, we also conducted a "Trader-Treatment", where we investigate an additional trading possibility (sellers were allowed to buy from other sellers). Furthermore, we conducted a "Backstop-Treatment". In particular, we introduced a backstop technology in the model, which is an unlimited substitute technology (renewable energy) offered to a certain price to the buyers. We test the behaviour of the sellers to examine whether the existence of a backstop technology could speed up the resource consumption which would exacerbate the climate change problem.

Conclusions

In contrast to earlier studies, we want to use a new approach to analyse the intertemporal dynamic allocation problem for an exhaustible resource. We find that the sophisticated task is solved better than expected by humans through a market process.
Economic experiments could thus provide a substantial contribution if other methods reach their limits to verify an economic theory. Therefore, the experimental method is a useful complement to the traditional empirical research.

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[2] We define marginal prices as prices that occur in the last 30 seconds of each 3 minutes lasting period as we want to perform the analysis with settled prices.
[3] In 1982, Smith calls his findings of high efficient double auction markets a "scientific mystery" (Smith 1982).