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Strategic resource extraction and substitute development☆

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ABSTRACT

We analyze a dynamic game between a buyer and a seller of a nonrenewable resource. The seller chooses resource supply; the buyer can pay a fixed cost to invent a perfect substitute for the resource at any time. In closed-loop equilibrium, the buyer adopts the substitute when the resource is exhausted. Investing makes the buyer worse off because it decreases resource supply, destroys his ability to derive surplus from the resource through delaying the investment cost incurrence, and causes a larger share of the resource stock to be sold at his reservation price. From the seller's perspective, the buyer's ability to develop a substitute is equivalent to an already available substitute with a higher marginal cost.

1. Introduction

The oil market has flavours of a bilateral monopoly. The largest exporters have united themselves in OPEC, a cartel that controls more than 75% of proven reserves[1] and actively manages supply. Importing countries coordinate on energy policy and energy security issues through various international organizations such as the IEA, OECD and EU, and cooperate in the development of renewable alternatives.

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[1] Known reserves that with reasonable certainty can be recovered in the future under existing economic and operating conditions. Source: BP Statistical Review of World Energy 2012.

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Consuming countries are vulnerable to monopoly power because of their heavy dependency on oil, but also have the means to end this dependency through developing a backstop: a substitute that can replace oil as the dominant energy source.

To prolong consumers' dependence on their resource, oil exporters have an incentive to prevent prices from becoming too high. Indeed, one of OPEC's aims is to 'secure an efficient, economic and regular supply of petroleum to consumers'. Conversely, importing countries realize that investment in alternative energy sources, such as shale gas or renewable energy, is not only a remedy to the physical scarcity of oil, but also affects exporters' supply decisions. The resulting strategic interaction is the subject of this paper: we ask how a nonrenewable resource seller can adjust the supply path to preserve its monopoly, and how a buyer can optimally use the ability to develop a substitute.

A key feature of nonrenewable resource markets is that expectations about future demand affect current supply. A binding promise by the buyer in the initial period about the arrival time of the substitute (Dasgupta et al., 1983; Gallini et al., 1983) will therefore not only change market conditions when the substitute comes on line, but also affect the supply path in all preceding periods (Karp and Newberry, 1993). As time passes, the effect on supply at the beginning of the time horizon becomes sunk, so the buyer faces a different trade-off than in the initial period. As a result, the buyer's optimal open-loop strategy is not time-consistent (Olsen, 1986, 1993): the buyer has an incentive to commit to late development in order to depress current prices, but would like to renege on his promise when the resource becomes scarce (see Section 3). Sellers who are sufficiently rational to calculate dynamic equilibria are unlikely to be naive enough to believe announcements that are not credible. In order to present a realistic model of their supply decision, it is important to exclude non-credible promises by the buyer. The contribution of this paper is to derive the closed-loop solution to the investment and supply game.

We use a simple model and a highly stylized representation of the innovation process. In each period, a monopolistic seller makes a supply offer to a buyer. After observing the seller's offer, the buyer decides whether to pay a fixed investment cost and develop a perfect substitute. Upon investment, the substitute can immediately be produced at constant marginal cost and competes with the resource. We abstract from uncertainty, capacity constraints, R&D externalities and imperfect cartelization in order to focus on the strategic aspects of the resource supply and innovation decisions.

In equilibrium, the seller induces the buyer to delay the adoption of the substitute until the resource is exhausted. When the buyer cannot commit to future actions, his only means to influence current supply is to invest immediately. Doing so adversely affects the buyer in three ways. Firstly, the seller immediately reduces supply following investment. Secondly, the buyer loses the ability to benefit from the resource through saving the interest on the investment cost. Thirdly, a larger share of the remaining resource stock is sold at the buyer's reservation price. From the seller's perspective, the buyer's ability to develop a substitute is equivalent to an already available substitute with a higher marginal cost.[2] Like in Hoel (1978), the seller limit-prices at the buyer's reservation price, which is higher than the marginal cost of the substitute because of the fixed investment cost. The buyer's indifference condition for investment only becomes binding when the remaining resource stock is sufficiently small.

The paper highlights the importance of the timing of moves. When the buyer moves after the seller in each period, he is able to punish the seller for supplying a low quantity. This threat disciplines the seller and allows the buyer and seller to attain a higher surplus compared to when the buyer invests immediately. If the buyer must decide whether to invest before observing the seller's quantity – as in Olsen (1993) – this disciplining device is unavailable, prompting the buyer to develop the substitute before the resource is exhausted.[3] Our timing accords better with the sustained and mutually beneficial relationship between buyers and seller in the oil market, as well as the slow progress in renewable

[2] The idea that potential competition resembles actual competition has a long tradition in industrial organization (Bain, 1956; Sylos Labini, 1957). The link between periods through the stock sets the resource market apart however: it creates a time-inconsistency for a consumer-surplus-maximizing entrant, and drives the immediate reduction in market supply when the buyer invests.

[3] Fujiwara and Long (2011) and Fujiwara and Long (2012) explore the importance of timing when the buyer can levy a tariff on the resource, instead of being able to develop a substitute. The welfare ranking of different timing structures depends on whether the seller sets prices or quantities.