Available online at www.sciencedirect.com
ScienceDirect
Resource and Energy Economics 30 (2008) 428–454
RESOURCE and ENERGY ECONOMICS
www.elsevier.com/locate/ree

An 'oil'igopoly theory of exploration

John R. Boyce [a,*], Lucia Vojtassak [b,1]

[a] Department of Economics, University of Calgary, 2500 University Drive, N.W., Calgary, Alberta, Canada T2N 1N4
[b] Department of Economics, Trent University Peterborough, Ontario, Canada K9J 7B8

Received 13 September 2006; received in revised form 10 October 2007; accepted 11 October 2007
Available online 22 October 2007

Abstract

This paper develops a theory of 'oil'igopoly exploration of an exhaustible resource. Strategic exploration and production are jointly derived in a three period subgame perfect equilibrium. While the 'oil'igopoly theory of exploration shares many features with non-strategic models of exploration and production, there is one important difference. The 'oil'igopoly theory of exploration predicts that firms who exhaust their proved reserves before they can convert their unproved reserves into proved reserves have an incentive to over-explore, relative to the Nash equilibrium level of exploration. A simple empirical prediction is that firms holding smaller proved reserves should be observed doing more exploration. This prediction is consistent with country-level production and reserve data in the post-World War II era.

JEL classification: Q30; L71; C73

Keywords: Oligopoly; Exploration; Exhaustible resources; Dynamic consistency

1. Introduction

The theory of 'oil'igopoly, developed by Salant (1976) and extended by Loury (1986) and Polasky (1992), has the simple yet elegant prediction that firms holding larger proved reserves tend to produce quantities which are larger in absolute size but smaller as a proportion of their reserves. Polasky found support for this prediction using data on proved reserves and production

* Corresponding author. Tel.: +1 403 220 5860.
E-mail addresses: boyce@ucalgary.ca (J.R. Boyce), luciavojtassak@trentu.ca (L. Vojtassak).
[1] Tel.: +1 705 748 1011x7257.

0928-7655/$ – see front matter
doi:10.1016/j.reseneeco.2007.10.001

in a cross-section of oil producing nations. However, there are two aspects of the theory of 'oil'igopoly that limit its general appeal.

The first of these limitations is that the results are derived using the Nash equilibrium concept rather than the subgame perfection equilibrium concept.[2] It is well known that the Nash equilibrium to dynamic games is not generally dynamically consistent. When the resource stocks are commonly owned, Levhari and Mirman (1980) and Reinganam and Stokey (1985) found substantial differences between the time paths of production in the Nash and subgame perfect equilibriums. However, Eswaran and Lewis (1985) showed that when firms possess well defined property rights, the Nash equilibrium differs only slightly from the subgame perfect Nash equilibrium.[3]

The theory of 'oil'igopoly also ignores exploration. When exploration is added to the game, it is no longer clear that the Nash equilibrium will yield results that are qualitatively similar to the dynamically consistent subgame perfect equilibrium.[4] The reason for this difference can be seen if one views exploration as the costly process of moving reserves from the "unproved" to the "proved" state, then exploration may have strategic implications.[5] This happens because once exploration occurs, the exploration costs become sunk. As exploration costs are on the order of hundreds of thousands of dollars for a well drilled on land to millions of dollars for a well drilled at sea, sinking the exploration cost results in a substantial lowering of the marginal cost of production.[6] By lowering its marginal costs of future production, a firm has a credible threat to its rivals that it will produce a larger quantity in the next period.[7] This threat induces one's rivals to tilt their production profile towards the present, which raises the present value of future production to the firm.

This paper examines a model of 'oil'igopoly exploration and production using subgame perfection as the equilibrium concept. Our first objective is to ascertain the conditions under which firms strategically use exploration to affect the behaviour of their rivals. Given that an

[2] Salant (1981, 1982), Lewis and Schmalensee (1980) and Ulph and Folie (1980) have also used Nash strategies to model the world oil market. See Mason and Polasky (2005) and Benchekroun et al. (2006) for recent extensions to the Nash model. See Gilbert (1978), Newbery (1981), Groot et al. (1992, 2003) for Stackelberg cartel-fringe models. Karp (1984), Maskin and Newbery (1990), Karp and Newbery (1993) consider Stackelberg models in which governments extract rents from exhaustible resource industries over time. These models also focus on the difference between open loop (Nash) and dynamically consistent (subgame perfect) equilibria.

[3] For example, if demand is linear, $p = \alpha - \beta Q$, and costs are quadratic, $c(q) = (\gamma/2)q^2$, then the solutions to the two period problem are independent of proved reserves, R_1 and R_2, which means that the Nash and subgame perfect equilibria in a game of more than two periods coincide exactly so long as the firms produce the same number of periods. Polasky (1992, no. 1, p. 217), citing Stiglitz (1976) claims that when marginal costs are constant and demand is iso-elastic, the Nash and subgame perfect equilibria also coincide. In the asymmetric game considered by Eswaran and Lewis (1985, Table 1, p. 466), the larger firm's output varied between −4.4 to +1.6%. The smaller firm's output varied from −1.1 to −4.4% in the first three periods, but by almost 30% in the final period in which it operated.

[4] Competitive models of exploration appear in Pindyck (1978), Arrow and Chang (1982), and Swierzbinski and Mendelsohn (1989).

[5] Proved reserves are those reserves for which exploration has already demonstrated the existence of an economically viable deposit. Unproved reserves are those reserves that the geologic indicators suggest exist, but which have not yet been discovered, or transformed into proved reserves, through exploration.

[6] Average drilling costs in the United States were approximately seven hundred thousand dollars for an onshore well and over twelve million dollars for an offshore well in 2002. *Source*: *Basic Petroleum Databook*, American Petroleum Institute, 2006.

[7] The strategic advantage conveyed by exploration is similar to that obtained from an increase in plant capacity, or R&D research to lower production costs in the industrial organization literature (e.g., Dixit, 1980, 1986; Fudenberg and Tirole, 1984; Bulow et al., 1985). The literature on strategic investments is surveyed in Tirole (1990, pp. 314–336).