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Non-renewable resource Stackelberg games☆

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ABSTRACT

The market structure for many mineral industries can be described as oligopoly with potential for Stackelberg leadership. This paper derives and analyzes dynamically consistent extraction equilibria in a two-period discrete-time "Truly" Stackelberg (TS) model of non-renewable resource extraction, where firms move sequentially within each period and where both the leader and follower have market power. We show how the leader may be able to manipulate extraction patterns by exploiting resource constraints. Whether the leader wants to speed up its own production relative to the Cournot–Nash (CN) equilibrium depends on the shape of its iso-profit curve, which is affected by the two firms' relative stock endowments and relative production costs. If the leader extracts faster, then the follower extracts slower, but in aggregate the industry extracts faster. Unlike static Stackelberg games, the follower does not necessarily have a second mover disadvantage.

1. Introduction

This paper is motivated by evidence that the supply-side of the market for many major minerals is dominated by a few large firms surrounded by one or more other relatively large firms. Table 1 shows that the market structure for ten important minerals is clearly oligopolistic, since the top five firms

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Table 1
Market share of the world's top 5 companies for major minerals production (% of world production).

Mineral	1st	2nd	3rd	4th	5th	Top five
Aluminium	Rusal 11%	Alcan 10%	Alcoa 9%	CHINALCO 8%	Norsk Hydro 4%	HHI = 382 42%
Copper	Codelco 11%	Freeport 9%	BHP Billiton 7%	Xstrata 6%	Rio Tinto 4%	HHI = 303 37%
Diamond	Anglo 24%	Alrosa Gropu 20%	Botswana 13%	BHP Billiton 7%	Rio Tinto 6%	HHI = 1230 70%
Gold	Barrick 9%	Newmont 7%	AngloGold 5%	Freeport 3%	GoldCorp 3%	HHI = 173 27%
Nickel	Norilsk 19%	CVRD 13%	Jinchuan 8%	Xstrata 7%	BHP Billiton 5%	HHI = 668 52%
Phosphate	Morocco 15%	Mosaic 11%	Tunisia 5%	PotashCorp 4%	Jordan 4%	HHI = 403 39%
Platinum	Anglo 36%	Impala 25%	Lonmin 11%	Norilsk 11%	Aquarius 4%	HHI = 2179 87%
Silver	BHP Billiton 6%	Fresnillo 5%	KGHM 5%	Pan American 3%	Goldcorp 3%	HHI = 104 22%
Tin	Yunnan Tin 18%	PT Timah 16%	Minsur 14%	Thaisarco 10%	Malaysia 8%	HHI = 940 66%
Zinc	Korea Zinc 8%	Nyrstar 7%	Hindustan 5%	Xstrata 4%	Glencore 4%	HHI = 170 28%

Source: Calculated by the authors based on U.S.G.S. (2011). HHI is the Herfindahl–Hirschman Index, HHI = $\sum_{i=1}^{5} s_i^2$, where s_i is the percent share of world production from each firm.

account for more than half of world production for four minerals (diamonds, nickel, platinum, and tin), and for more than a third of world production for seven minerals, including aluminium, copper, and phosphate.[1] Furthermore, in the platinum, diamond, nickel, and tin industries the largest firm controls nearly a fifth of the market or more, and the size of the second largest firm in these industries suggests many mineral industries may more closely resemble a Stackelberg leader-follower relationship rather than either a dominant-firm/competitive-fringe (DF) or a Cournot–Nash (CN) framework. For these highly concentrated mineral markets with a potential for Stackelberg leadership, the evolution of market production is especially important for those manufacturers that depend upon a reliable supply of these minerals. Therefore, it is important to understand how the equilibrium extraction patterns are determined under such a market structure.

This paper derives the dynamically consistent equilibrium to a two-period discrete-time non-renewable resource model in which the leader moves before the follower within each period in choosing its output and in which both the leader and the follower act as price searchers. This Truly Stackelberg (TS) model differs from CN models by the leader-follower sequencing of production choices within each period, and it differs from DF models both by the leader-follower sequencing of production choices and by the price searching behavior of the follower. While the DF and CN equilibria have been extensively characterized in the literature, the TS equilibria has no antecedent.[2] Relative to both the CN and DF equilibria, the TS game exhibits a much richer set of equilibria.

When firms have stocks sufficient to last at most two periods, the equilibria may be analyzed using simple piece-wise best-response functions in two-dimensional graphs. This allows us to clearly highlight the effect of differences in resource constraints and extraction costs on the equilibrium selection by the leader. In addition, using discrete periods allows us to differentiate between sequential-move

[1] The 4-firm HHI index for these minerals range from 104 for silver (very competitive) to 2163 for platinum, which is sufficiently concentrated that in the U.S. government approval would be required for mergers.

[2] There exists a fourth class of games which we do not consider here: sequential-move DF equilibria, where the leader moves first within each period but the follower is a price searcher. These equilibria, however, are quite different from the TS equilibria we study. In those games, with a price taking follower, the follower's reaction to an increase in the leader's output is to decrease his output by one unit for every unit increase in the leader's production. This has the effect that the leader's strategic effect on the follower exactly offsets the effect he has upon market price, hence both the leader and follower implicitly act as price takers in equilibria in which the follower produces over both periods.