Industry Dynamics in Common-Pool Resources: Lessons from American Whaling

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This paper investigates strategic industry dynamics in common-pool resources, where firms experience turnover. Theories predict that competitive participation and capitalization lead to external diseconomies over time. Rising market prices, resulting from cost increases, would further incentivize these tendencies. To analyze these economic forces, I estimate a dynamic model using data from the American whaling industry. Leveraging the estimated model parameters, I quantify the welfare loss in comparison to the optimal outcome of a social planner and evaluate various counterfactual policies.

Keywords: common-pool resources, productivity, dynamic games, regulation, American whaling industry

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"[I]n former years (the latter part of the last century, say) these Leviathans, in small pods, were encountered much oftener than at present, and, in consequence, the voyages were not so prolonged, and were also much more remunerative"

Moby-Dick, Melville (1851), Chapter 105

1. Introduction

How does open access shape inefficiencies in common-pool resources? This question has been a central economic concern in various real-world scenarios, such as fishing, livestock grazing, carbon emissions, and groundwater extraction (Lloyd 1833; Coman 1911; Gordon 1954; Hardin 1968; Ostrom 1990).[1] In an open-access system, resource users freely enter, invest, and exit. This freedom can be detrimental because the greater the number of users, the higher the negative externalities. Hence, understanding the endogenous evolution of market structure is crucial for managing common-pool resources. This paper contributes to this understanding by analyzing the behaviors of firms in the American whaling industry, which relied on shared resources, namely whales.

The US whale fishery holds historical significance and empirical interest for several reasons.[2] First, the absence of regulation provides a unique setting for an open-access environment. In contrast, contemporary contexts often involve regulatory practices with data collection, making it hard to study in a pure open-access system (e.g., Squires et al. 2010; Huang and Smith 2014; Ho 2022). Second, it provides micro-level data that enables the identification of firms' entry, exit, and vessel operations. This is particularly valuable given the challenges of systematic data collection with low excludability of common-pool resources. The dataset covers the industry's entire lifespan, allowing for observations of firm birth and death that would not be feasible with contemporary data (e.g., Huang and Smith 2014; Sears, Lin Lawell, and Walter 2022).

This paper develops a Ericson and Pakes (1995)-style model of dynamic games for examining strategic industry dynamics in common-pool resources. I extend the model

[1] In small communities, collective self-governance would be feasible to address these issues by excluding use from outside the community (Ostrom 2010). However, as society has grown in scale, commons problems have extended beyond individual communities and even crossed national boundaries with open access or full non-excludability (Stavins 2011). Inadequate resource management has led to over-exploitation, as evidenced by studies such as Costello et al. (2012, 2016) in the context of global fisheries.

[2] During the 1850s, the industry ranked as the fifth largest in the United States, with a value of $10 million in 1880 dollars, mainly due to its oil production. By that time, New Bedford, the leading whaling city, stood as the wealthiest city per capita in the country (Davis, Gallman, and Gleiter 2007). Whaling was Massachusetts' third largest industry in 1850, and it held the fourth place in 1860 (Moment 1957).

to capture the endogenous entry, exit, investment, market prices, and resource growth in equilibrium. Under open access and rivalry conditions, two externalities may exist. First, a congestion externality arises from excessive vessels, firms, and harvesting efforts, as participants rush to exploit the resource ahead of others. Second, a stock externality emerges due to overexploitation, reducing the resource stock available for the future. If these forces persist, the aggregate supply declines. Consequently, market prices rise, influencing behaviors related to exit and divestment.

To make the point, Figure 1 presents the two-stage dynamics of firms and the market. In the stage one (upper panel), the non-excludability and rivalry of the commons prompt firms to enter the market until they reach the break-even point A, assuming a competitive environment where firms are price-takers. This leads to resource overuse beyond the maximum sustainable yield ($Q_{\text{msy}} < Q_1$).[3] The left figure of stage two (lower panel) depicts that firm costs increase due to congestion externality (resulting from too many firms) and resource externality (resulting from stock decline). With the original market price p_1 and the new marginal cost curve MC_2, the firm is expected to exit as point B falls below the shutdown point. However, as shown in the right figure of stage two, the market supply curve shifts leftward from S_1 to S_2 as all firms share the resource and face increased costs in the commons. Consequently, firms now receive the new price p_2, which is above the shutdown point. Instead of exiting, the new equilibrium at point C enables firms to produce q_2, resulting in a market production of Q_2.

From this graphical analysis, key insights stand out: (1) excessive entry and investment, (2) competition and resource over-exploitation, (3) cost increases, and (4) delayed exit and divestment influenced by market response. The non-excludability and rivalry inherent in the commons lead to negative externalities through entry and investment choices. Despite cost increases, some firms persist in the market delaying exiting or divesting if prices reach a sufficiently high level. This exacerbates market inefficiencies if Q_2 is realized at a higher than desired level. Therefore, understanding and addressing the commons problem requires a focus on the dynamics of decision-making.

Consistent with these predictions, Figure 2 provides descriptive evidence in the US whale fishery. Panel A of Figure 2 displays the quantity of output, measured by the number of whales harvested per vessel.[4] Following a sharp increase in the 1800s-1820s,

[3] In renewable resources, such as fisheries, the maximum sustainable yield refers to the highest annual harvesting level that can be maintained over time.

[4] Section **??** outlines the conversion rule from the whaling products (sperm oil, whale oil, and whalebone) to the number of whale catch.

FIGURE 1. Dynamic inefficiencies in the commons

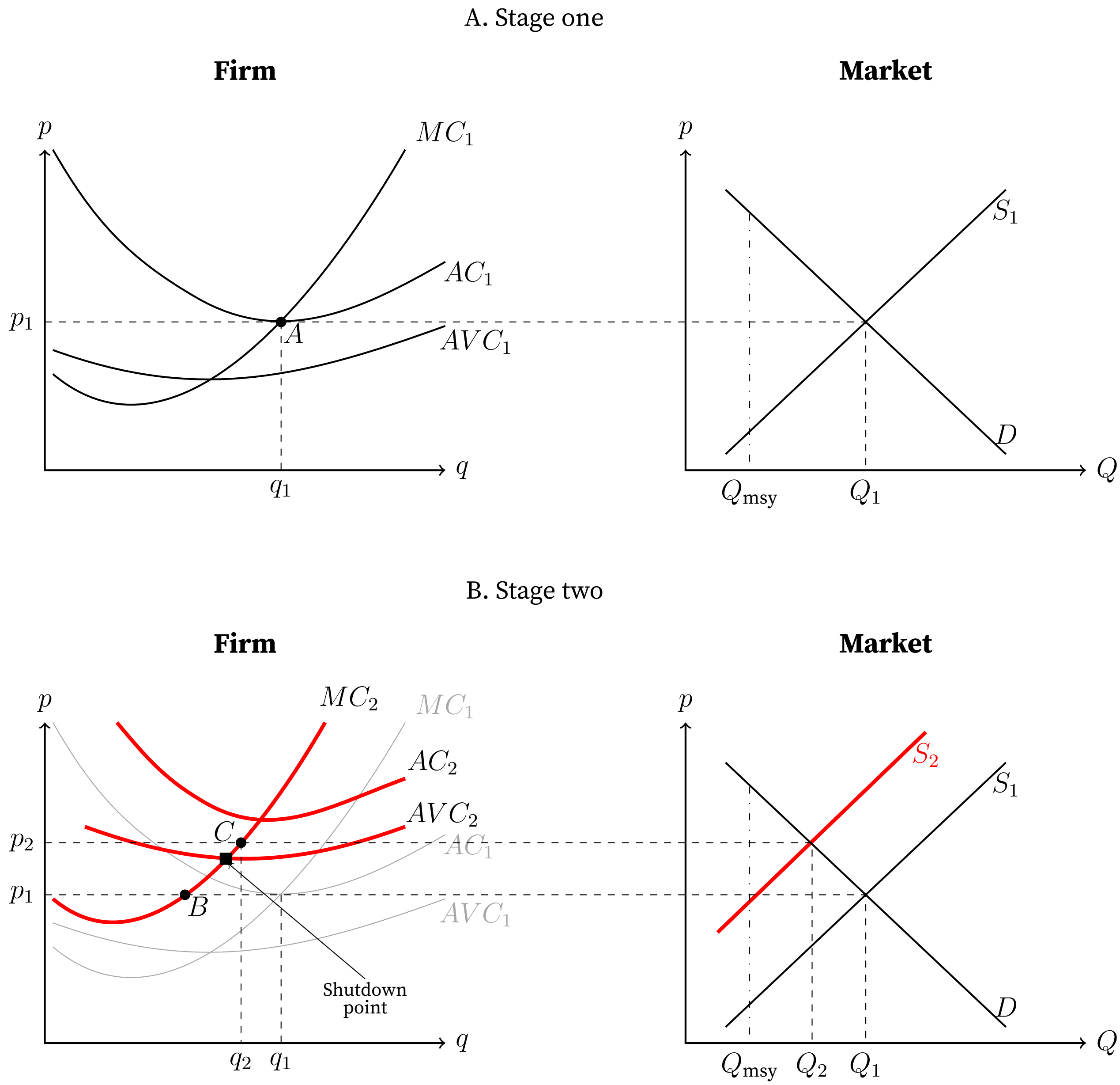
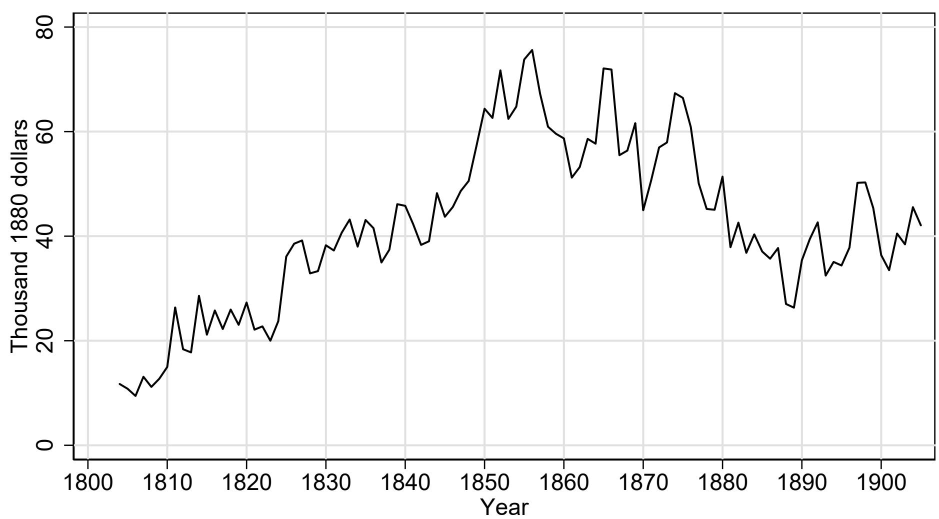


FIGURE 2. Output and revenue per vessel

A. Output: The number of whales harvested

B. Revenue: The value of output



Notes: In panel A, the output is measured by the number of harvested whales. In panel B, the value of output is calculated as the sum of the product values: sperm oil quantity × sperm oil price + whale oil quantity × whale oil price + whalebone quantity × whalebone price.

the production quantity per vessel declines.[5] It reached around 60 during the 1820s and reduced to 44 in the 1860s. It is particularly noteworthy to observe such a decline when considering the overall technological growth over time. That is, there exist negative externalities arising from congestion and resource scarcity, as depicted by reduced q in Figure 1 (from q_1 to q_2). On the other hand, panel B of Figure 2 demonstrates a significant increase in revenue due to rising prices during the period of production decline.[6] In the 1820s, the average revenue per vessel was \$30,000, which increased to \$66,000 in the 1860s.[7] Although the quantity of output decreased, the price increase was sufficient to generate higher revenue. This suggests the presence of incentives for firms to continue operating despite cost increases.

The main challenge to this investigation is the large number of firms in the industry. The open-access and rivalry feature naturally involves many firms in the commons.[8] This makes the application of Ericson and Pakes (1995)-type model infeasible due to the curse of dimensionality. To address this issue, I employ the oblivious equilibrium proposed by Weintraub, Benkard, and Van Roy (2008). The model assumes that whaling firms form beliefs about the future evolution of the resource stock and industry, based on their competitors' optimal strategies. Each firm has a negligible impact on industry dynamics, but their effects accumulate in aggregate. To accommodate the evolution of demand and whale population, I apply a nonstationary oblivious equilibrium (NOE) by Weintraub et al. (2008), rather than stationary equilibrium.

This paper estimates the profit and cost structure of the industry, using the two-step estimation approach proposed by Bajari, Benkard, and Levin (2007).[9] The first step involves estimating the production function, demand curve, and policy functions. To consistently estimate production parameters, I apply the dynamic panel approach to address the correlation between firms' productivity and their input decisions. Additionally, to address potential unobserved demand factors that could affect demand curves, supply-side cost shifters are used as instruments to estimate the price elasticity of demand. The policy functions that govern exit and investment decisions are also flexibly estimated. In the second step, expected value functions for incumbents are obtained through a forward simulation method that utilizes the estimated results

[5]Production outputs seem to vary from year to year. In some years, the catch was poor, while in other years, new grounds would be discovered and large catches were recorded (Moment 1957).

[6]The series of prices is displayed in Figure **??**.

[7]The values are evaluated in 1880 dollars.

[8]Firms enter and operate as long as break-even point A is achieved in Figure 1A.

[9]I am working on full-solution approach via nested-fixed point (NFXP) algorithm (Rust 1987). It will be updated soon.

from the first step. Based on these simulated value functions, the costs of investment and disinvestment, along with the distribution of entry fixed costs and exit values, are recovered by imposing equilibrium conditions.

The estimated cost structure sheds light on the underlying frictions in the industry, explaining the asymmetric capacity adjustment and entry-exit problems. These asymmetries arise from the endogenous price and whale population dynamics in response to firm behaviors. Consequently, divestment or exit from the industry does not yield the same value as the initial investment or entry cost, leading to delayed divestment and exit. This persistence of excess capacity is attributed to the presence of sunk costs, making it easier to invest and enter but harder to divest and exit.

The asymmetric cost structure gives rise to multiple inefficiencies in the industry. Firstly, there is significant heterogeneity in firm productivity, with coexistence of less productive and more productive firms. This suggests the potential for reallocating resources towards more productive firms to enhance overall industry efficiency. Secondly, there is a growing dispersion in marginal product of capital and product over time, indicating dynamic inefficiency as less productive firms operate larger capacity over time.

Building on a comprehensive understanding of the profit-cost structure, this paper aims to conduct counterfactual experiments. As a benchmark, the social planner maximizes aggregate consumer and producer surplus to quantify welfare loss. Additionally, the effects of policy remedies are evaluated, focusing on two market institutions: Pigouvian tax and cap-and-trade mechanisms.

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