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Industry Dynamics with Cartels: The Case of the Container Shipping Industry*

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Industry Dynamics with Cartels: The Case of the Container Shipping Industry*

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Abstract

I investigate how explicit cartels, known as "shipping conferences", in a global container shipping market facilitated the formation of one of the largest globally integrated markets through entry, exit, and shipbuilding investment of shipping firms. Using a novel data, I develop and construct a structural model and find that the cartels shifted shipping prices by 20-50% and encouraged firms' entry and investment. In the counterfactual, I find that cartels would increase producer surplus while slightly decreasing consumer surplus, then may increase social welfare by encouraging firms' entry and shipbuilding investment. This would validate industry policies controlling prices and quantities in the early stage of the new industry, which may not be always harmful. Investigating hypothetical allocation rules supporting large or small firms, I find that the actual rule based on tonnage shares is the best to maximize social welfare.

1 Introduction

The ocean-going shipping industry, as a main engine in international trade, has developed to this day, bearing the burden of the nation's rise and fall. The history of the industry is older than that of competition law. So, the international practice has been based on the "principle of freedom of shipping," i.e., not giving priority to the transport of cargo to and from one's own country by one's own merchant fleet and ships of one's own flag. It has been an international practice for governments not to intervene in the choice of shipping

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companies and vessels. Under this principle, the ocean-going shipping industry has developed in many countries around the world without much regulation of market entry, exit, or business activities. In addition, for more than 130 years, consortia and international cartels have been formed among shipping companies, and these cartels have been allowed in most countries.[1] In the shipping industry, international shipping cartels are called "shipping conferences," which control shipping prices and quantities of member firms by centralized decisions of the members.[2] The breakdown of shipping conferences caused drops in shipping prices in the 1980s, historically known as the "container crisis" (Broeze 2002). This paper disentangles the effect of the cartel breakdown on prices, firms' entry, shipbuilding investment, and welfare by analyzing the shipping conferences.

Global containerization which refers to the use of standardized shipping containers to transport goods around the world changed the industrial structure. Global containerization has the effect of dramatically lowering the entry barriers for new shipping companies in developing countries. In addition, the existence of shipping conferences became strongly perceived as an impediment to the entry of developing countries' shipping industries into the world trade market. In response to this trend, in 1974, the United Nations Convention on the Charter of the Liner Shipping Union was concluded and allowed new shipping companies to participate in shipping conferences.

While containerization was progressing, as part of the deregulation policy under the Reagan administration in the United States, the new Shipping Act was enacted in June 1984. Its aim was first to allow member carriers to make individual agreements with shippers on freight rates and services, and second to unbind shippers from shipping alliances so that shippers could make their own choices of shipping companies. As a result, the enactment led to a change from the collusive regime by shipping conferences controlling shipping prices and quantities to the competitive regime.

Although the industry has been the subject of policy debates for about 150 years, quantitative research has been limited. To overcome data limitation, I construct a unified dataset based on several published books and publicly available data sources and study the relationship between industry growth and cartels, in particular, collusive markups and inner allocation mechanism within cartels.[3] Concretely, I explore how global containerization and explicit cartels formed one of the largest globally integrated markets via entry,

[1] The Transport Policy Council (2007) of the Ministry of Land, Infrastructure and Transportation in Japan defines a shipping conference as an agreement on freight rates and other business matters to restrain competition among container shipping lines for the same routes. A consortium is a technical agreement between several shipping lines to form a group and operate a joint service for services diversification, a reduction in the investment scale, and a cost reduction in the liner service. In addition, consortia include alliances that are widely used.

[2] There is an important difference between shipping conferences and alliances: Conferences are organized by specific routes and directions, while alliances are formed globally. There may exist one conference covering trade on the transatlantic route and another covering trade between Northern Europe and US Gulf ports. In addition, firms do not always participate in conferences on all routes and directions they serve. Thus, conferences are very heterogeneous in their structure and membership.

[3] See Otani and Matsuda (2023a) for more information on data construction.

exit, and shipbuilding investment of shipping firms by exploiting the route-year-level variations of freight rates, shipping quantities, and competition regimes.

Using the new dataset, I analyze the historical shipping price reductions in the 1980s known as the "container crisis" (Broeze 2002). It is anecdotally known that the crisis has been associated with two events: (1) the withdrawal of Sea-Land, which was the largest cartel member from shipping cartels in 1980 and (2) the enactment of the Shipping Act of 1984. The first event changed the market share of shipping cartels significantly, while the second event neutralized the shipping cartels. To motivate my structural model, I evaluate the effect of the above two events on shipping prices using regressions. I find that after the two events, shipping prices decrease by 51%, which illustrates the effect of the industry regime on shipping prices during 1966-1990.

However, it is not possible to disentangle the different explanations for the observed price reduction using only reduced-form regression results. Therefore, I focus on the period between 1973 (i.e., the post-Oil-Shock period in the main three markets) and 1990 (i.e., before the initial year of the strategic alliances) and construct a dynamic structural model of firms' entry, exit, and investment decision in homogenous good markets under collusive and perfect competition regimes, which are exogenously determined by the enactment of the Shipping Act of 1984. Understanding the effect of shipping conferences with a structural model contributes to the literature on competition law and industrial policy which have been investigated in the shipbuilding and shipping industry (Kalouptsidi 2017, Barwick *et al.* 2019, Juhász *et al.* 2023).

I construct a structural model with explicit cartels. In the static competition analysis, I extend Porter (1983) to estimate cartel effects when firms and researchers are aware of the transition from a collusive market regime to a competitive one. In the dynamic competition analysis, I apply the sequential dynamic game approach proposed by Igami (2017) to market-year-level data on entry, exit, and investment, when the market regimes are known. For each set of candidate parameters, I solve firms' entry, exit, and investment problems for a type-symmetric perfect Bayesian equilibrium (PBE) using backward induction. Then, I construct the likelihood of observing the actual choices in the data and estimate parameters maximizing the likelihood, rationalizing the observed entry, exit, and investment patterns.

Under static competition, I find that cartels increased shipping prices by $1,106 before 1979 and $440 during the 1980-1983 period. Specifically, cartel effects led to approximately a 20% increase in prices on the Asia-to-Europe route before 1979 and a roughly 50% increase on the transatlantic westbound route. Under dynamic competition, market heterogeneity in dynamic parameters can explain the observed data patterns. Furthermore, I find that the estimated investment costs for all markets are higher compared to previous studies on the global HDD industry (Igami 2017) and the recent container shipping industry (Jeon 2022), which reflects the unique high sunk costs in shipbuilding and collusive pricing during the early stages of the industry.

In counterfactual simulations, I evaluate the welfare performance of policies regarding cartel effects and inner allocation. Specifically, I analyze how the cartel effects and inner allocation mechanism would impact entry, exit, and shipbuilding through the shifting static profit function. First, prohibiting cartels affects firms' entry and shipbuilding investment, but the impacts are economically small due to the inelastic demand and large dynamic sunk costs relative to the present discounted value of the static markup in future periods. Second, prohibiting cartels would not always lead to an increase in social welfare prior to 1984. This is due to smaller profits, which in turn leads to a decrease in the number of firms entering the market and investing in shipbuilding, resulting in a smaller market-level capacity and shifting up the supply equation while shifting down the equation by neutralizing the cartel effects. This finding may provide an empirical justification for industry protection policies that involve price and quantity control through a centralized mechanism in the early stages of a new industry and underscore dynamic considerations that are necessary to assess welfare. Third, I find that the actual inner allocation rule of shipping conferences based on tonnage shares is the best to maximize social welfare. Specifically, under the hypothetical inner allocation rule supporting large firms, producer surplus would increase, and consumer surplus would decrease, then social welfare would decrease. Also, under the hypothetical inner allocation rule supporting small firms, producer surplus would slightly decrease, and consumer surplus would not change, then social welfare would not change at an economically significant level.

Related literature This paper contributes to three strands of the literature, namely, the analysis of the effect of an explicit cartel, market dynamics of investment and entry/exit, and recent industrial policy and antitrust studies in the shipping industry. As far as I know, this paper is the first paper combining explicit cartels and investment dynamics with known and simple inner allocation rules.

First, this paper empirically evaluates the effect of the shipping cartel on the market outcome and welfare. While several papers empirically investigate the consequences of welfare under cartels in several industries and auction formats using structural models, see the recent survey by Asker and Nocke (2021), this paper focuses on the shipping conferences as a single explicit cartel entity, and departs from the traditional focus on tacit collusion in the literature, e.g., Porter (1983), Bresnahan (1987), Miller and Weinberg (2017), and Byrne and De Roos (2019). This paper contributes to the empirical literature on explicit cartels. Several cartels have been analyzed as case studies, for example, sugar production (Genesove and Mullin 1998, 2001), Norwegian domestic cement cartels (Röller and Steen 2006), bidding rings (Asker 2010b), gasoline pricing (Clark and Houde 2013, 2014), global coffee cartels (Igami 2015), collusive beer pricing (Miller and Weinberg 2017), trade association of gynecologists (Alé-Chilet and Atal 2020), global oil industry (Asker *et al.* 2019), global vitamin cartels (Igami and Sugaya 2022), and Joint Operating Agreements in the U.S. local daily print newspaper industry (Tiew 2022). Each of these studies investigates specific features of each cartel.

Shipping cartels studied in my paper are recognized in survey papers such as those by Levenstein and Suslow (2006), and Asker and Nocke (2021). Some studies, such as those of Morton (1997) and Podolny and Morton (1999), examine the specific shipping cartels in the UK in the 1800s. Wilson and Casavant (1991) provide evidence on the regime change by the Shipping Act of 1984 using quarterly data of freight rates and shipping quantities of five selected commodities only on the transpacific route. However, they do not exploit cross-sectional variations, especially between non-US and US routes. My data contain cross-sectional variations of the freight rates. Thus, to the best of my knowledge, due to data limitations, no papers investigated shipping cartels on six main routes after the global containerization in the 1970s.

The institutional background and approach are close to Igami (2015). Igami (2015) studies the impact of market power on international coffee prices and evaluates the effect of a cartel treaty on coffee prices and its global welfare consequences under counterfactual competition regimes, i.e., collusion versus Cournot–Nash in a single homogenous good market. Miller and Weinberg (2017) adopt a similar strategy for a specific merger to test a conduct parameter between Bertrand–Nash and collusion in the US beer industry in differentiated goods markets. Clark and Houde (2013, 2014) study explicit price-fixing cartels in the Canadian gasoline market by applying a differences-in-differences (DID) approach to collusive and competitive markets. I cannot use a DID approach on my data because the cartel breakdown impact may propagate in the whole industry. Like these papers, I exploit the regime change of the whole industry caused by the exogenous cartel breakdown events.

Second, this paper contributes to the literature on industry dynamics with a model including firms' decisions on entry, exit, and investment. The shipbuilding investment size and technology adoption are closely related in the container shipping industry because the size of a container ship captures technology generation. Specifically, new generation ships are known as "Panamax" ships because of the size limits for ships traveling through the Panama Canal. As the size of the capacity increases, the marginal cost of shipping decreases. Each firm determines each year whether to pay a fixed cost to build large-capacity ships or not conditional on the number of firms for each log-capacity level. Empirical applications include Ryan (2012), Igami (2017), and Igami and Uetake (2020). My paper complements their findings with shipping cartels inducing the collusive markup and inner allocation mechanism.

Third, this paper connects to the industry's history from its beginning to its development after 2000, which has gained attention in the industrial organization literature (Aguirregabiria *et al.* 2021).[4] The most

[4]The ocean shipping industry before the introduction of global container transportation is also studied. For example, Otani (2021) investigates Japanese shipping consolidation in 1964 by a structural matching model.

relevant paper is Jeon (2022). She examines the relationship between demand uncertainty and firm-market-year-level investment decisions by using container shipping demand and freight rate data between 1997 and 2014. To facilitate her learning-based model, she needs to obtain initial prices and demand in the container industry. Due to data limitation, she considers imputation and truncation approaches for missing shipping demand data from 1966:Q2 to 1996:Q4 and confirms that the truncation approach performs well. Unlike this paper, I use actual data and model shipping cartels explicitly. On cartel issues in a similar industry, the most relevant paper is Asker (2010a). He studies how the presence of a cartel affects market conduct following its dissolution, and how the dissolution might be affected by the obligations imposed on firms who seek leniency in the tanker shipping market between 2001 and 2002. Kalouptsidi (2014), Brancaccio *et al.* (2020), and Greenwood and Hanson (2015) investigate the bulk shipping industry after 2000. Bai and Li (2021) study the tanker market during 2017-2020 and investigate how the imbalance between the demand and supply of shipping services determines congestion. Although these industries are closely related to the container shipping industry, each of these industries is differently characterized because market structure and competition are different. Also, Kalouptsidi (2017) and Barwick *et al.* (2019) study the shipbuilding industry, which is an upstream industry for the container and bulk shipping industries. These papers rely on the use of the Clarksons Research database and focus on the period after 2000.

This paper provides quantitative insights into the anecdotal evidence and theoretical models discussed in the literature on maritime economics. As a unified survey, Sjostrom (2013) finds that most work on shipping conferences has involved four kinds of models: monopolistic cartels, contestable markets, destructive competitive, and empty cores. From the viewpoint of the industrial organization literature, the choice between these models determines the pre-act supply-side behavior involving a markup. Regarding the Shipping Act of 1984, Pirrong (1992) tests the model prediction of core theory using data of two specific trade routes between 1983 and 1985. Clyde and Reitzes (1998) study the relationship between market power and the market share of shipping conferences after the act.

In the international trade literature, Bernhofen *et al.* (2016) use country-level panel data on containerization adoption for the period 1962–1990. They focus on the effect of containerization adoption on the trade quantity, so they refer to *the Containerization International Yearbook* only for obtaining the first presence of container technology in each country. Rua (2014) adds port-level data to their study and investigates the diffusion of initial adoptions of containerized transportation. Coşar and Demir (2018) exploit rich Turkish export data and examine modal choice between containerization and breakbulk shipping. My paper complements their findings by providing firm-market-year-level evidence and investigates market dynamics and welfare. Like these papers, I exploit the change in competition regimes associated with the Shipping Act.

2 Data and institutional background

I provide details about the data in Section 2.1. I introduce the institutional background of the shipping conference and the early history of the container shipping industry and discuss two key events associated with the change of competition regime in Section 2.2.

From the point of view of a firm's entry and exit decisions, a *market* in this industry is a non-directional location pair, i.e., if a firm operates a container ship in the eastbound of the transpacific, then it should operate the ship in the westbound. A *route* is a directional trip, e.g., westbound and eastbound of the transpacific.

2.1 Data

I use route-year-level and firm-market-year-level data of the container shipping industry. I define an operator firm and a group as a firm. Each route (market) is divided into conference and non-conference routes (markets). For example, the transatlantic eastbound conference route is a single route and the transatlantic conference market is a single market. A conference market is a market where all conference firms conducted collusive behavior under the shipping conferences before the Shipping Act, but have competed since then. A non-conference market is a market where all non-conference firms compete throughout the whole period. As far as I know, price data in non-conference markets are not available.[5] In this paper, I treat the non-conference markets as competitive fringe markets, remove them from the model, and focus solely on the conference market.

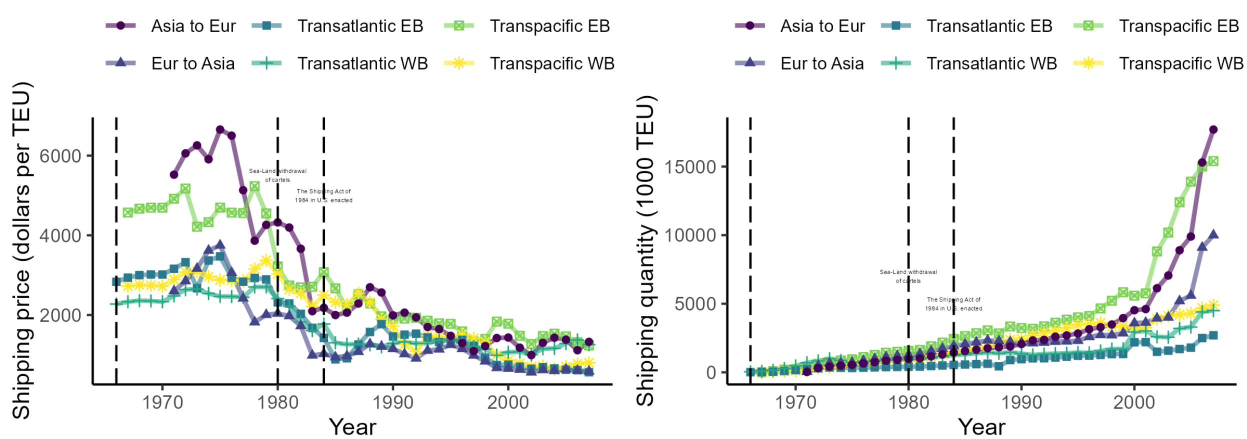
Shipping prices and quantities First, I use route-year-level data of container freight rates and shipping quantities for the conference routes. Collecting these data, in particular before 1994, is not trivial because there is no single data source that covers the period between 1966 and 1993. Otani and Matsuda (2023a) provide various data sources and a detailed guide on data construction for each of the container freight rates and shipping quantities on major six routes: mainhaul and backhaul (separately) on the transpacific (Asia and North America), transatlantic (North America and Europe), and Asia-Europe routes. Finally, I use price and quantity data in the six conference routes between 1966 and 2009. Prices are adjusted by the U.S. CPI in 1995.

Figure 1 illustrates the nonstationary trends of container freight rates and shipping quantities in the conference routes between 1966 and 1990. Container freight rates decrease with fluctuations and suddenly

[5] Based on interviews with ex-practitioners in shipping companies, container freight rates for nonmember carriers were 20% to 30% lower than conference firms on the same routes. However, there was no data available on the trends in freight rates offered by the non-conference carriers. In addition, although I checked *The Japan Maritime Daily*, the newspaper of the maritime industry, I could not find any articles that continuously reported onfreight rates offered by non-conference carriers.

drop tremendously. However, the transitions of freight rates on Asia-Europe eastbound (Europe-to-Asia) and westbound (Asia-to-Europe) routes are more unstable than that on transpacific and transatlantic routes in the 1970s and 1980s. It might be because the strength of the shipping conference on the Asia-Europe route declined, and its impact was more significant.[6] The conference shipping quantities in all routes increase monotonically between 1973 and 1990.[7]

The withdrawal of Sea-Land and enactment of the Shipping Act of 1984 in the US divide the conference market's regime, which is illustrated in the trend of the container freight rates in Figure 1. Under the legislation of the Shipping Act of 1984 in the US, shipping conferences were easier to form and lost privileges. Also, after 1984, the transpacific and transatlantic routes experienced severe price reductions via market competition. The change of the industry regime shaped the container crisis.



(a) Price

(b) Quantity

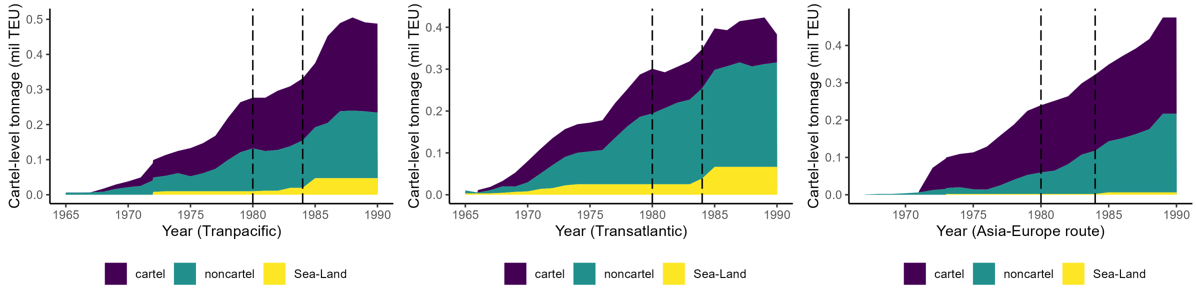
Figure 1: The trends of the container freight rates and shipping quantities.

Note: The container freight rates before 1992 refer to conference prices. The container freight rates after 1993 are the unified prices based on the conference and non-conference prices, and the difference between them is known to be vanished due to the Shipping Act of 1984. The latter data are standard and are often used in the literature such as Jeon (2022).
Sources: Otani and Matsuda (2023a)

Tonnage share across conference and non-conference markets Second, I use ship-level data from a series of *the Containerization International Yearbook* (CIY). I use the information on the build year, the name of the ship operator, the deployed route, and the shipping capacity measured by the twenty-foot equipment units (TEU). I assign the main three routes (that is, transatlantic, transpacific, and Asia-Europe) to all ships

[6]Based on an interview with an ex-executive of a Japanese shipping company, conferences related to Asia-Europe had a strict membership screening process, and the number of voyages by member companies was clearly defined (closed conference). In addition, some members of the conference pooled their freight and then redistributed them. In contrast, the conferences for transpacific routes were free to join or leave (open conference), and freight pooling was explicitly prohibited under the Shipping Act of 1916 in the US.

[7]See Otani and Matsuda (2023a) for an analysis on the trends of the freight rate and quantity after 1990. It is anecdotally known that the decrease of shipping prices between 1976 and 1978 might be caused by the reopen of Suez canal.



(a) Transpacific (b) Transatlantic (c) Asia-Europe

Figure 2: Conference and non-conference market shares in the whole industry

Note: Conference and non-conference market shares are calculated by the tonnage share of ships deployed in the westbound and eastbound of the market. I highlight the market share of Sea-Land, which had a key role in the conference market.
Sources: *Containerization International Yearbook*

deployed on the routes, including subareas. Almost all ships are deployed in eastbound and westbound routes in each assigned route.[8] I combine the ship-level data with the firm-market-year-level data of entry/exit in the market and joining/leaving conference and non-conference markets from various data sources.[9]

Based on the tonnage share of the firm-market-year-level data, I calculate the shipping tonnage shares of the conference and non-conference firms.[10] For example, the transatlantic eastbound route has conference and non-conference routes independently. Figure 2 illustrates the transitions of market shares of the conference and non-conference firms and Sea-Land in each market, aggregating eastbound and westbound routes. Throughout all periods, the transatlantic market was competitive because of the growing number and size of non-conference firms. In contrast, the Asia-Europe market was dominated by conference firms, particularly before 1980. The transpacific market is the middle case. Remarkably, the withdrawal of Sea-Land from shipping conferences would affect the change of conference shares because it had the largest share in the transpacific and transatlantic markets.

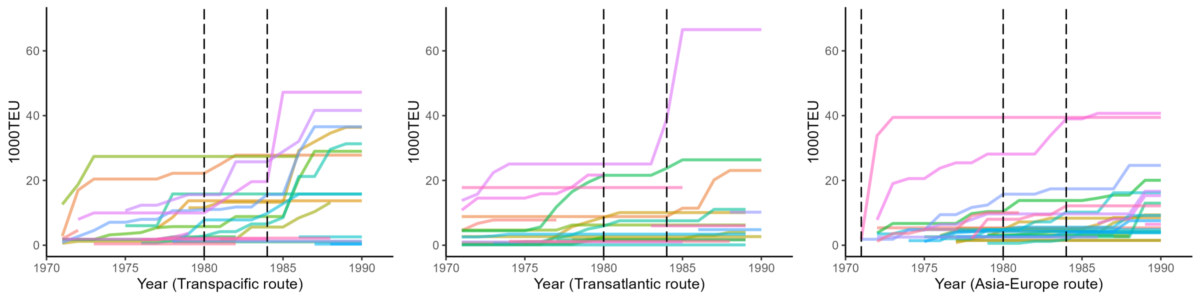
Investment pattern within a conference market Figure 3 shows firm-year-level investment patterns measured by TEU in each conference market except for Sea-Land. First, the largest firm remained in the same position for many years. Second, almost all active firms accumulated tonnage size, and investment booms and patterns are similar within each market. These two features not only provide an actual dynamic

[8] The tonnage of ships deployed in multiple main routes is treated as the shipping capacity in "Multiple" routes and omitted in the analysis because I could not identify the allocation of deployed ships to multiple routes. The ships deployed in multiple routes were going to be common only after 1980. Thus, the effect of omitting these ships is limited.

[9] See Otani and Matsuda (2023a) for additional details. This uses (Department of Transportation, the United States 1992, Maritime Industry Research Institute 2004, Pace 1981, Gilpin 1983, Van Ham *et al.* 2012) and information from the website of the port of Long Beach (https://polb.com/port-info/timeline/). See the industry-year-level merger patterns between 1966 and 2022 in Otani and Matsuda (2023b).

[10] In the literature, the shipping quantity share is approximated by the capacity share because the utilization rate was high. For example, in one of the oldest data, the utilization rate in the transpacific was 60% to 100% between 1997 and 2000 (https://www.mol.co.jp/ir/data/cfh/pdf/data0105_2.pdf) even in the mature stage of the industry. I could not find evidence that firms strategically controlled utilization rates before 1990.

equilibrium path but also help state discretization in the dynamic estimation part. See Section 3.



(a) Transpacific (b) Transatlantic (c) Asia-Europe

Figure 3: Firm-market-year-level capacity transition

Sources: *Containerization International Yearbook*

Table 1: Summary statistics of route-year-level and market-year-level variables

	N	mean	sd	min	max
Quantity in conference route (1 mil TEU): Q_{rt}	138	0.61	0.47	0.00	2.05
Quantity in nonconference route (1 mil TEU): Q_{rt}^{non}	138	0.42	0.33	0.00	1.30
Price in conference route ($1000 per TEU): P_{rt}	138	2.79	1.23	0.89	6.65
Log ($ GDP of destination area): X_{rt}	138	28.26	0.73	26.33	29.42

Market	Type		mean	sd	min	max
Asia and Eur	Cartel	Num of firms: N_{mt}	20.93	4.68	2.00	25.00
		Total tonnage (1 mil TEU): S_{mt}	0.19	0.05	0.00	0.26
	Noncartel	Num of firms: N_{mt}	28.12	8.91	2.00	37.00
		Total tonnage (1 mil TEU): S_{mt}	0.11	0.07	0.00	0.21
Transatlantic	Cartel	Num of firms: N_{mt}	14.90	2.58	6.00	17.00
		Total tonnage (1 mil TEU): S_{mt}	0.11	0.04	0.01	0.18
	Noncartel	Num of firms: N_{mt}	81.67	26.15	3.00	102.00
		Total tonnage (1 mil TEU): S_{mt}	0.18	0.07	0.00	0.25
Transpacific	Cartel	Num of firms: N_{mt}	14.70	3.91	1.00	19.00
		Total tonnage (1 mil TEU): S_{mt}	0.17	0.09	0.00	0.31
	Noncartel	Num of firms: N_{mt}	30.36	8.67	4.00	38.00
		Total tonnage (1 mil TEU): S_{mt}	0.12	0.06	0.01	0.19

Note: The data spans 25 years (1966-1990) for six routes. Transatlantic routes opened in 1966, transpacific routes in 1967, and Asia-Europe routes in 1971. For panel (b), the shipping prices before 1992 refer to conference prices, while the shipping prices after 1993 are the unified prices based on the conference and non-conference prices and the difference between them vanished due to the Shipping Act of 1984. The latter data are standard and are often used in the literature such as Jeon (2022).
Sources: *Containerization International Yearbook and Otani and Matsuda (2023a)*

Table 1 shows the summary statistics of route-year-level and market-year-level variables. The subscripts r, m, and t are the route, market, and year index, respectively. It displays the route-year-level variables of the conference and non-conference shipping quantities Q_{rt} and Q_{rt}^{non}, conference shipping price P_{rt}, and GDP of the destination area, X_{rt} between 1966 and 1990. Also, it countains the number of firms, N_{mt} and total tonnage, S_{mt} in each market. The key feature is that the number of firms in non-conference markets

Table 2: Summary statistics of firm-market-year-level variables

(a) Firm-market-year-level variables of conference firms (1966-1990)

Market		mean	sd	min	max
Asia and Eur	Num of ships	5.57	4.59	1.00	20.00
	Total tonnage (1000 TEU)	8.87	10.04	0.60	40.70
	Quantity share: q_{imt}/Q_{mt}	0.05	0.08	0.00	0.57
	Quantity share: q_{imt}/Q_{mt}^{whole}	0.04	0.06	0.00	0.47
Transatlantic	Num of ships	7.59	7.46	1.00	36.00
	Total tonnage (1000 TEU)	7.35	10.62	0.10	66.55
	Quantity share: q_{imt}/Q_{mt}	0.07	0.09	0.00	0.50
	Quantity share: q_{imt}/Q_{mt}^{whole}	0.04	0.05	0.00	0.32
Transpacific	Num of ships	9.60	8.28	1.00	28.00
	Total tonnage (1000 TEU)	11.08	11.76	0.31	47.22
	Quantity share: q_{imt}/Q_{mt}	0.08	0.12	0.00	1.00
	Quantity share: q_{imt}/Q_{mt}^{whole}	0.04	0.05	0.00	0.27

(b) Firm-market-year-level variables of non-conference firms (1966-1990)

Market		mean	sd	min	max
Asia and Eur	Num of ships	3.99	4.92	1.00	30.00
	Total tonnage (1000 TEU)	3.42	5.05	0.11	28.01
	Quantity share: $q_{imt}^{non}/Q_{mt}^{non}$	0.05	0.09	0.00	0.88
	Quantity share: $q_{imt}^{non}/Q_{mt}^{whole}$	0.02	0.07	0.00	0.88
Transatlantic	Num of ships	3.17	3.18	1.00	26.00
	Total tonnage (1000 TEU)	2.15	3.14	0.10	29.81
	Quantity share: $q_{imt}^{non}/Q_{mt}^{non}$	0.02	0.04	0.00	0.54
	Quantity share: $q_{imt}^{non}/Q_{mt}^{whole}$	0.01	0.02	0.00	0.34
Transpacific	Num of ships	4.63	4.50	1.00	24.00
	Total tonnage (1000 TEU)	3.55	5.20	0.13	32.37
	Quantity share: $q_{imt}^{non}/Q_{mt}^{non}$	0.04	0.06	0.00	0.53
	Quantity share: $q_{imt}^{non}/Q_{mt}^{whole}$	0.02	0.04	0.00	0.51

Note: The large market shares capture the early stage of the industry where only a few active firms exist.
Sources: *Containerization International Yearbook*

is larger and the average tonnage is smaller than in conference ones, which implies that the assumption of competitive fringe is reasonable.

Panel (a) in Table 2 shows firm-market-year level variables in the conference markets for the number of ships, total tonnage, and shipping quantity share as measured by tonnage size relative to the conference market and whole market, q_{imt}/Q_{mt} and q_{imt}/Q_{mt}^{whole}. The mean of the number of ships varies from 5.57 to 9.60. The mean quantity share in the conference market is 5.57% in the Asia-Europe market, 7.59% in the transatlantic market, and 9.6% in the transpacific market. Panel (b) in Table 2 displays firm-market-year level variables in the non-conference markets. The average non-conference shipping quantity shares in the whole market are less than half of conference ones. This again suggests that the assumption of competitive fringe is reasonable as in the market-year-level data.

2.2 Industry Background

I provide some key features of shipping conferences, that is, an internal mechanism for conference firms and an external mechanism for non-conference firms. See Otani and Matsuda (2023a) for additional details. Before introducing the container shipping industry, I summarize the shipping conferences in the liner shipping industry whose subset was a container shipping industry at that time.

Shipping conferences The main purpose of shipping conferences in the liner shipping industry is market stabilization by controlling entry via excess capacity (Fusillo 2003), predatory pricing (Morton 1997, Podolny and Morton 1999), price discrimination (Fox 1992, Clyde and Reitzes 1998), loyalty contracts (Marin and Sicotte 2003), and so on. To this aim, the shipping conferences agreed on a variety of other issues between the shipping companies in addition to freight rates. The content of the agreements can be roughly divided into three categories: (1) alternatives to suppress freight rate competition among the member shipping companies, (2) alternatives to prevent the outflow of shippers to non-conference shipping companies, and (3) alternatives to directly exclude non-conference vessels.

To avoid freight rate competition, rate agreements and vessel allocation agreements are concluded among member shipping companies. The rate agreements are signed by conference members to agree on rates for each product and to update rates jointly. The vessel allocation agreements adjust the amount of tonnage to be allocated, the number of voyages, ports of call, operation schedules, and cargo to be loaded. These features have been modeled as price and quantity-fixing cartels. According to *United Nations Conference of Plenipotentiaries On A Code Of Conduct For Liner Conferences*, the service quantity was determined based on the tonnage capacity share.[11] This feature is incorporated in the supply side model of Section 3.

[11]See *United Nations Conference of Plenipotentiaries On A Code Of Conduct For Liner Conferences* published by United

Conference tariff rates (freight rates) decided by these agreements had public notice, and no specific entry restrictions were imposed on the ocean shipping market. Thus, the market is always subject to competition from non-conferences' vessels and new entrants. For this reason, the shipping conferences introduced the Dual Rate System, the Fidelity Rebate System, and the Differed Rebate System to ensure the effectiveness of the freight rate agreements and prevent shippers from flowing to non-conference shipping companies that offered lower rates than the conferences' tariff rates.[12] These systems are recognized as entry deterrents to promote the stability of the freight rate and liner services.[13]

Conferences also used "fighting ships," which are vessels temporarily put into service at a similar schedule as non-conference shipping companies and at lower rates.[14] Fighting ships were used to force non-conference shipping companies to leave the route. All the members shared the losses associated with the operation of fighting ships.

On the modeling across conference and non-conference markets, I assume that non-conference markets are competitive fringe markets. That is, I treat non-conference markets out of the model. Also, I assume that shippers' decisions on the use of conference or non-conference ships are exogenous. That is, I treat the demand for shipping as a variable in the data. These assumptions are needed due to the data limitation and are restated in Section 3.

After the 1960s, the circumstances and nature of shipping alliances rapidly changed. In particular, shipbuilding investment was centered on containerizations explained later and pro-competitive amendments to shipping laws in the United States have had a major impact on the functioning of shipping alliances and market competition in the shipping market.

The history of container shipping began with Malcolm P. McLean, the founder of the US land transporta-

Nations in 1975. Section *Article 2, PARTICIPATION IN TRADE, 5* in this article provides that, *"If, for anyone of the countries whose trade is carried by a conference, there are no national shipping lines participating in the carriage of that trade, the share of the trade to which national shipping lines of that country would be entitled under article 2, paragraph 4 shall be distributed among the individual member lines participating in the trade in proportion to their respective share."* The issue of national shipping concerns trade between developed and developing countries. In the three main markets in this period, my data contain no national shipping. Thus, this statement applies to my paper.

[12]In the Dual Rate System, a shipper and a shipping conference conclude an exclusive patronage contract/loyalty agreement and provide transportation service for the specific route. The contract rate is lower than the spot rate under the condition that the shipper uses only conference member carriers' service within a specific contract period. The Fidelity Rebate refunds a portion of the freight if the shipper uses only the conference carriers within a specified period (4-6 months). The Differed Rebate System is also an incentive to use conference carriers. Under the system, if a shipper had used only members' services for a specified refundable period (4-6 months), and if it does not use any non-conference members' service for the deferment period following the refundable period, a certain amount of money is refunded upon the shipper's request. The refund amount was usually around 10% of the freight. Fox (1992) uses the US port pair-level data in 1977 to examine the effect of the dual rate contract and consumer loyalty.

[13]For instance, Marin and Sicotte (2003) examine the economic effects of exclusive contracts of ocean shipping cartels during the 1950s between firms and the ultimate consumers of their product. They record that, "During the congressional investigations of shipping conferences in the late 1950s and early 1960s documents obtained from an ocean carrier contained an admission that 'the entire contract system is a fighting measure to get rid of outside competition' " (p.198).

[14]See Marshall and Marx (2014) (page 148) and Harrington *et al.* (2018) for reference to put the strategy of shipping conferences in general cartel literature. Harrington *et al.* (2018) classify the general response of cartels to the expansion of non-cartel supply into four strategies: takeover, starvation, coercion, and bribery. The fighting ships are classified into coercion strategy.

tion company Sea-Land Service. The first international container ship was employed by Sea-Land Service for the transatlantic route in 1966, and for the transpacific route in 1967. For the Asia-Europe route, the first international semi-container ship, the Cornelia Maersk, was employed in 1967. However, the first international full-container ship, the Kamakura-maru, was delayed to start in 1971, which is recognized as the first year of global containerization. Dissemination of container shipping called global containerization induced the following market changes between 1966 and 1990: (1) transforming the cost structure, (2) lowering barriers to entry, and (3) stimulating the rise of (non-conference) shipping companies in developing countries. See Otani and Matsuda (2023a) for details on each point.

Withdrawal of Sea-Land from shipping conferences in 1980 In the last years of the 1970s, a substantial increase in competition for transpacific routes put pressure on rates. In 1979, Sea-Land introduced eight SL-7 high-speed container vessels with a speed of 33 knots. These vessels worsen the profitability of the company. The company withdrew from the shipping alliance to ensure its profitability.

However, because of the conference's dual freight rate system, shippers who had contracts with conference carriers were unwilling to pay the penalty to switch to Sea-Land. At the time, the double freight rate system did not cover only port-to-port cargoes. Therefore, Sea-Land focused on import shippers and intermodal cargoes that were not covered by the double-freight rate system. In addition, the fact that Sea-Land paid the freight cost of returning containers from inland to the port rather than passing them on to shippers has led to a reduction in freight rates.

The Shipping Act of 1984 in the US In the U.S., the new Shipping Act was enacted in June 1984 as part of the deregulation policy under the Reagan administration. The aim of the act was to allow member carriers to make individual agreements with shippers on freight rates and services and to unbind shippers from shipping alliances so that shippers could make more appropriate choices. It drastically changed the competition regime, especially in the US-related routes.[15]

First, the Shipping Act of 1984 included the mandatory right to Independent Action (IA). IA refers to a behavior that a member firm may define independently its freight rates or services that deviate from the conference tariff rates. It guaranteed the right for the member carriers of the shipping conference to set their own rates or services different from those of the alliance under the principle of openness.

Second, the act required conferences to allow the right to form service contracts (SC). SC refers to a contract in which the shipper commits in advance to load a specific quantity or more of cargo to the shipping company during a specific period. Under this contract, the shipping company reserves the space necessary

[15] Wilson and Casavant (1991) provide anecdotal evidence and a case study of the effect of the Shipping Act of 1984.

to carry the cargo and applies discounted freight rates.[16]

Third, the act prohibited the Dual Rate System. As such, the shipping conference lost its binding power on shippers, and individual shipping companies frequently exercised their right of independent action, which encouraged competition among shipping companies and led to a significant decline in freight rates on US-related routes.[17]

2.3 Reduced form evidence on the Container Crisis

I quantify the effect of the withdrawal of Sea-Land and Shipping Act of 1984 on the shipping prices.[18] I use data of six routes between 1973 and 1990 to quantify the changes in the container freight rate before and after the competition regime change induced by the Act. I drop data before the 1973 oil crisis and after 1991 because of the Soviet collapse in 1991 and the next deregulation act, the Ocean Shipping Reform Act (OSRA) of 1998.

I quantify the effect of the withdrawal of Sea-Land and Shipping Act of 1984 by least squares with dummy variables for the two events, which are 1 after the event and 0 otherwise. I incorporate the variations of the difference of cost shifters, that is, crude oil price, and specify the log container freight rate P_{rt} in route r in year t as:

$$\log P_{rt} = \beta_1 \mathbb{1}(\text{after 1980})_{rt} + \beta_2 \mathbb{1}(\text{after 1984})_{rt} + \beta_3 \log X_{rt} + \beta_4 \log W_{rt} + \tau_r + \xi_{rt},$$

where $\log X_{rt}$ is the log of GDP for the destination area, $\log W_{rt}$ is the log of a mile-weighted crude oil price, τ_r is a route fixed effect, and ξ_{rt} is assumed to be an i.i.d. error term. We estimate parameters $\beta_1, \beta_2, \beta_3, \beta_4$, and τ_r.[19]

Table 3 reports the regression results. The coefficients in Model 1 indicate that the withdrawal of Sea-Land from cartels in 1980 decreased the container freight rate by 43% (i.e., $\exp(-0.570) - 1 = -0.43$). Model 2 also indicates that the enactment of the Shipping Act of 1984 decreases the container freight rate by 43% (i.e., $\exp(-0.556) - 1 = -0.43$). Model 3 includes both dummy variables and shows that the after-1984 dummy explains the part of the price reduction given by the coefficient of the after-1980 dummy.

Models 4, 5, and 6 include route fixed effects and provide similar signs of the coefficients for the after-1980 and after-1984 dummies. Incorporating route fixed effects significantly increases the adjusted R^2 and

[16] The minimum number of containers promised by the shipper to the shipping company is called the MQC (Minimum Quantity Commitment).

[17] Japan Maritime Center (2008) pointed out that the Dual Rate System was the most effective way shipping companies kept their shippers when the conference system was functioning.

[18] Otani and Matsuda (2023a) show that a structural break test reveals that the container crisis occurred around 1980 in all routes and the Shipping Act of 1984 heterogeneously boosted the container crisis in the US routes.

[19] Note that adding fixed effects controlling unobserved heterogeneity within a year induces an overparametrization problem of the coefficients of dummy variables in my route-year-level panel data.

Table 3: Changes in log of the cartel's freight rates, P_{rt}.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1(after 1980)	-0.570**		-0.491**	-0.424**		-0.420**
	(0.177)		(0.150)	(0.087)		(0.074)
1(after 1984)		-0.556**	-0.404**		-0.306+	-0.296*
		(0.197)	(0.151)		(0.142)	(0.111)
log GDP: $\log(X_{rt})$	-0.047	-0.100	0.151	-0.226+	-0.349+	-0.015
	(0.161)	(0.159)	(0.229)	(0.098)	(0.144)	(0.161)
log(crude oil price): $\log(W_{rt})$	0.179***	-0.159	-0.018	0.152**	-0.051	0.018
	(0.027)	(0.107)	(0.066)	(0.038)	(0.056)	(0.031)
Route FE				X	X	X
Num.Obs.	108	108	108	108	108	108
R2	0.437	0.375	0.485	0.804	0.757	0.824
R2 Adj.	0.421	0.356	0.465	0.789	0.737	0.808
Std.Errors	by: route	by: route	by: route	by: route	by: route	by: route

Note: Estimation is with OLS. The dependent variable is the route-year-level average of the log of freight rate measured by US dollars (adjusted to 1995 CPI) per TEU. The sample covers the period between 1973 (i.e., after the 1973 oil shock) and 1990 for six markets. Significance levels are denoted by $^{+}p < 0.1, ^{*}p < 0.05, ^{**}p < 0.01$, and $^{***}p < 0.001$. The numbers between parentheses give the standard errors, which are clustered at the route level.

reduces the levels and standard errors of the dummy variables by controlling market-year-level unobserved heterogeneity. Model 6 shows that the withdrawal of Sea-Land from cartels in 1980 decreases the container freight rate by 34% (i.e., $\exp(-0.420)-1 = -0.34$) and the enactment of the Shipping Act of 1984 additionally decreases it by 26% (i.e., $\exp(-0.296) - 1 = -0.26$). The composite effect of the two dummies shows that after the container crisis of 1984, the price decreased by 51% (i.e., $\exp(-0.296 - 0.420) - 1 = -0.51$). Thus, estimation using a longer and route-year-level panel data suggests an overestimation of the effect of the Shipping Act of 1984, as discussed in previous studies such as Wilson and Casavant (1991).

The reduced-form analysis yields several important insights into the container crisis. However, there are several potential reasons for observing this pattern. For example, marginal costs may have changed over time. Alternatively, there may have been changes in the industry conduct. To disentangle these explanations and gain much more detailed insights into the different channels, I develop a structural model in the following section.

3 Model

I construct a structural model to investigate how the withdrawal of Sea-Land from cartels and the enactment of the Shipping Act of 1984 reduce container freight rates through the markup reduction of cartels and affect the entry/exit/investment dynamics in the industry. I assume that conference and non-conference routes are mutually independent both on demand and supply sides and treat non-conference firms as price takers in a competitive fringe. These assumptions provide a tractable model under limited data, i.e., without non-conference price data.[20] Also, because the non-conference markets consist of many small firms relative to the conference markets, the competitive fringe assumption is reasonable. Consequently, the shipping quantities of non-conference firms are excluded in the subsequent analysis. As before, I drop the data before the 1973 oil crisis and after 1991 because of the Soviet collapse in 1991 and the next deregulation act, i.e., the Ocean Shipping Reform Act (OSRA) of 1998.

I consider a finite horizon and a nonstationary environment. For each market in each year, incumbents and potential entrants observe a vector of all individual tonnages and exogenous demand as state variables. Then, the static profit determined by the state and cartel effect is realized. Given some specified order, each incumbent firm sequentially takes a discrete action from the action set consisting of exiting the market, staying in the market without investments, and staying with investments after observing all previous actions of all firms. Investment in this paper is shipbuilding investment increasing the tonnage size. After observing all actions of all incumbents, each potential entrant takes an action from the action set consisting of entering the market and exiting the market. After all firms decide actions, the state variables for the next year are updated based on their actions.[21] Thanks to the uniqueness of the equilibrium, I can solve the dynamic equilibrium backwardly as in Igami (2017, 2018).

3.1 Demand and supply

Demand Let Q_{mt}^{whole} and Q_{rt}^{whole} denote the total shipping amounts in market m in year t and directed route r in year t, respectively. The market demand consists of the eastbound and westbound of the route demand in market m. A container shipping route in route r in year t is divided into conference and non-conference routes, i.e., $Q_{rt}^{whole} = Q_{rt} + Q_{rt}^{non}$, where Q_{rt} and Q_{rt}^{non} are total shipping amounts of conference and non-conference firms, respectively. For example, the transatlantic route has transatlantic conference and non-conference routes. I do not model shipping customer behavior between conference and non-conference

[20] Recently, Clark *et al.* (2018), Gabrielli and Willington (2020), and Caoui (2022) study the interaction of partial cartels and non-cartel firms in auction formats and Harrington *et al.* (2018) study how the German cement cartel controlled the expansion of non-cartel supply from Eastern European countries. I do not consider strategic interactions between conference and non-conference firms because of the absence of non-conference price data.

[21] Similarities and differences of my paper from Igami's papers and Jeon (2022) are summarized as follows. Similarity with Igami's papers is in the dynamic part, that is, the equilibrium concept, key specification, and computational technique. The difference from Igami's papers is in the static part, i.e., cartel effects (ω_{imt}), and no static competition. Similarity with Jeon (2022) is static parts, that is, specifications of log-log demand and supply side without cartel. The difference from Jeon (2022) is the dynamic part, i.e., equilibrium concept, key specification, and computational technique. She incorporates learning of demand into "moment-based Markov equilibrium" with additional variables such as the backlog and charter data in 2006-2014. She solves the model by the full-solution method even under potential multiple equilibria. Her learning model finds that the initial condition problem is ignorable based on an AR(1) interpolation. However, her assumptions are questionable because the industry had cartels and nonstationary markets. Instead of her complicated model, I assume no learning and assume tractable type-symmetric Perfect Bayesian Equilibrium with a rational expectation of cartel breakdown.

shipping services.[22]

Let $P_{rt}(s_{rt}, D_{rt}, \zeta_{rt}, \eta_{rt})$ denote the conference shipping prices where s_{rt} is endogenous observed state capturing route-level capacities of all firms as defined later, D_{rt} is exogenously determined observed demand states, and ζ_{rt} and η_{rt} are i.i.d. demand and supply errors. Note that the errors are realized at the route-year-level, not at the firm-route-year level. [23] Let $Q_{rt}(s_{rt}, D_{rt}, \zeta_{rt}, \eta_{rt})$ and Q_{rt}^{non} be the demand function of conference and non-conference shipping. I assume that Q_{rt}^{non} is exogenously determined by fringe non-conference firms and focus on $Q_{rt}(s_{rt}, D_{rt}, \zeta_{rt}, \eta_{rt})$ in the estimation.

Demand for container shipping of conference firms in route r in year t, $Q_{rt}(s_{rt}, D_{rt}, \zeta_{rt}, \eta_{rt})$, is assumed to have constant elasticity and specified in the following parametrized form:[24]

$$Q_{rt}(s_{rt}, D_{rt}, \zeta_{rt}, \eta_{rt}) = \exp(D_{rt})(P_{rt}(s_{rt}, D_{rt}, \zeta_{rt}, \eta_{rt}))^{\alpha_1} \exp(\zeta_{rt}), \tag{1}$$

where α_1 is the parameter of the slope of the demand curve. I omit the i.i.d. errors ζ_{rt} and η_{rt} in the static equilibrium prices and quantities because these are numerically determined on average by numerical draws as in Igami (2017).

Supply Suppose N_{rt} firms exist in route r in year t. Each firm observes the state vector $(s_{rt}, D_{rt}) = (s_{irt}, s_{-irt}, D_{rt})$, where s_{irt} is the individual discretized endogenous state, i.e., firm-level tonnage size, s_{-irt} is tonnage size of firm i's rivals, $s_{rt} = (s_{irt})_{i=1}^{N_{rt}} = (s_{irt}, s_{-irt})$ is the industry discretized endogenous state, i.e., the vector of the individual discretized endogenous state, and D_{rt} is the industry discretized exogenous state. The discretization is discussed in the dynamic part. I assume that in the spot market, firms do not control capacity strategically given their capacity constraints (Jeon 2022).

[22]Customers can choose either or both conference and non-conference services. I collected data of whole quantity $Q_{mt}^{whole}(= Q_{mt} + Q_{mt}^{non})$ and recover conference and non-conference market quantity, Q_{mt} and Q_{mt}^{non}, as in the maritime literature. Concretely, the market (quantity) share of conference and non-conference service can be approximated proportionally by tonnage shares because the industry-level container utilization rate is 80-95% historically, and I did not find any evidence of a low utilization rate. Here, Q_{mt}^{non} is determined by the sum of individual service quantities out of the model. Finally, $Q_{mt} = Q_{mt}^{whole} - Q_{mt}^{non}$ is residual quantity determined by shipping conferences.

[23]Conference firms "follow" prices and quantities determined by shipping conferences. Non-conference firms "set" prices and quantities based on individual decisions so the price data do not exist because they did not need to be report their prices publicly. It is anecdotally known that the non-conference prices were lower than conference ones by 10-20% before 1984. Price differences even in the homogenous service markets come from safety, reputation, unobserved quality, inertia, rich options, and so on.

[24]I follow Kalouptsidi (2014) and Jeon (2022) in the static demand estimation. There are a few different points from these studies. First, my data do not contain quarterly-based variables before 1994, so my analysis is based on market-year-level observations. This ignores short-run fluctuation of container freight and shipping quantities. Second, my data observe the initial stage at which some price instruments used in these studies cannot be constructed. For example, the fraction of ships that are over 20 years old can be constructed only after 1986.

Individual supply equation Firm i's marginal cost giving service quantity q_{irt} is defined as

$$mc_{irt}(q_{irt}, s_{irt}) = \gamma_0 + \gamma_1 \frac{q_{irt}}{s_{irt}}, \tag{2}$$

where γ_0 and γ_1 are cost parameters. If γ_1 is positive, the marginal cost increases linearly as the firm's quantity decreases due to the difficulty of operations. If γ_1 is negative, the marginal cost decreases linearly due to the cost efficiency. I leave the sign of γ_1 as an empirical question. This specification assumes that cost heterogeneity comes only from service quantity and tonnage size and there is no firm-level unobserved heterogeneity. Also, note that the tonnage size s_{irt} is not exactly the firm-year-level shipping capacity because I do not observe service frequency. The total cost of shipping q_{irt} has the analytical form, $\int_0^{q_{irt}} mc_{irt}(q, s_{irt}))dq = \gamma_0 q_{irt} + \gamma_1 \frac{{q_{irt}}^2}{2s_{irt}} + C$ where C is a constant of integration. I assume that $C = 0$ and the constant cost is absorbed in the dynamic operation cost introduced later. Finally, note that the above marginal cost specification is critical and may be the only specification that allows share-weighted aggregation in a theoretically correct way and that other specifications using s_{irt} are not available.

In a competitive market, the market price equals route marginal cost (route MC) which is the sum of individual marginal costs (2) weighted by the tonnage share plus an i.i.d. route-year-level unobserved error η_{rt}:

$$P_{rt} = \sum_{i=1}^{N_{rt}} \frac{s_{irt}}{S_{rt}} mc_{irt}(q_{irt}, s_{irt}) = \underbrace{\gamma_0 + \gamma_1 \frac{Q_{rt}}{S_{rt}}}_{\text{route MC}} + \eta_{rt},$$

where $S_{rt} = \sum_{i=1}^{N_{rt}} s_{irt}$. This specification is similar to Porter (1983).

Firm i's static profit in route r in year t is defined as

$$\pi_{irt}(q_{irt}, s_{irt}, D_{rt}) = P_{rt}(s_{rt}, D_{rt}) q_{irt} - \int_0^{q_{irt}} mc_{irt}(q, s_{irt}))dq,$$

given demand state D_{rt}, tonnage capacity s_{irt} included in s_{rt}, and equilibrium price $P_{rt}(s_{rt}, D_{rt})$. Taking its first-order condition with respect to q_{irt}, I obtain $P_{rt}(s_{rt}, D_{rt}) = \gamma_0 + \gamma_1 \frac{q_{irt}}{s_{irt}}$. Solving this for q_{irt}, firm i's individual supply equation q_{irt} is defined by

$$q_{irt}(P_{rt}(s_{rt}, D_{rt}), s_{irt}) = \frac{P_{rt}(s_{rt}, D_{rt}) - \gamma_0}{\gamma_1} s_{irt}. \tag{3}$$

There are some remarks. First, aggregating individual supply equations gives route marginal cost, i.e., $Q_{rt} = \sum_{i=1}^{N_{rt}} q_{irt} = \frac{P_{rt} - \gamma_0}{\gamma_1} S_{rt}$ gives route supply equation, $P_{rt} = \gamma_0 + \gamma_1 \frac{Q_{rt}}{S_{rt}}$ without shipping cartels.

Second, all firms provide service quantities up to the level at which their marginal costs equate the price, i.e., $mc_{irt}(q_{irt}, s_{irt}) = P_{rt}$ for all i, and then obtain positive profits. Third, in the container shipping industry, the individual supply $q_{irt}(P_{rt}(s_{rt}, D_{rt}), s_{irt})$ is determined either by the allocation rule based on tonnage share before 1983 or the above individual supply equation after 1984. Next, I discuss the choice of modeling.

Route supply equation with and without cartel behavior The route supply equation is given as the capacity-share-weighted sum of all firms' supply equations plus the route cartel effect:

$$P_{rt} = \gamma_0 + \gamma_1 \frac{Q_{rt}}{S_{rt}} + \underbrace{\tilde{\gamma} 1(t \leq 1983)}_{\text{route cartel effect}}, \tag{4}$$

where parameter $\tilde{\gamma}$ shifts the route supply equation.

The idea of the route cartel effect is the same as Porter (1983). Unlike this paper, however, I am agnostic on the behavior of the shipping conferences which are explicit cartels with the breakdown timing known to firms and researchers. I treat the route cartel effect as a deviation from a competitive price. Shipping conferences shift up the original supply equation (i.e., route marginal cost) by route cartel effect as in Igami (2015). We can interpret as if they pretend to have higher marginal costs. The last term captures (partially) collusive markup directly instead of endogenizing (partially) joint profit maximization (i.e., the marginal revenue equals the marginal cost) in homogenous goods markets. Although the above direct approach is restrictive and gives no structural sense, I believe that endogenizing (partially) joint profit maximization is not a good approximation for shipping conferences for the following reasons. First, container shipping firms provide shipping services on fixed schedules between ports, so it might be difficult to adjust the total service quantity to some target level shipping. Second, conferences can control prices to compete with non-conference firms out of the model. Third, the assumptions of Porter (1983) that capacity information does not matter and the output shares of cartel members are relatively stable across the regimes are inadequate in my data of a nonstationary industry history as shown in Section 2. Fourth, as a practical reason, the collusive power as discussed in Section 2 is potentially time-varying and the sample size is not large enough to conduct parameter estimation (Bresnahan 1982), discussed in Matsumura and Otani (2023a,b,c). See Appendix C for the discussion of the trade-off of modeling choices and theoretical details. For the above reasons, I take a direct approach in which the cartel effect $\tilde{\gamma} 1(t \leq 1983)$ is a period effect that can be specified more flexibly even under small sample.

3.2 Equilibrium price, quantity, and profit in spot markets

The industry regime is exogenously determined by the Shipping Act of 1984 and classified into two types, i.e., collusive regime before 1983 and competitive regime after 1984.

Determinants of P_{rt} in competitive regime after 1984 After 1984, $P_{rt}(s_{rt}, D_{rt})$ is determined by an intersection of the demand and supply equations as perfectly competitive prices. Substituting (1) into (4) and solving the following for P_{rt} given (α, γ), we numerically obtain an equilibrium price $P^*_{rt}(s_{rt}, D_{rt})$ as follows: Solving numerically the following fixed point problem for P_{rt} given parameters, we obtain an equilibrium price $P^*_{rt}(s_{rt}, D_{rt})$.

$$P_{rt} = \gamma_0 + \gamma_1 \frac{\exp(D_{rt}) \cdot (P_{rt})^{\alpha_1}}{S_{rt}} + \underbrace{\tilde{\gamma} 1(t \leq 1983)}_{=0}.$$

Note that the fixed point is unique if $\alpha_1 < 0, \gamma_0 > 0$, and $\gamma_1 > 0$, that satisfy the standard downward demand and upward supply equations.[25]

Determinants of P_{rt} in collusive regime before 1983 Before 1983, shipping conferences consisting of all conference firms set total quantities and quotas. The equilibrium price P_{rt} is determined by the demand and price-quantity decision of shipping conferences. As discussed above, we do not explicitly model market-year-level price-quantity decisions of shipping conferences. Instead, the effect is captured by the cartel effect term in Equation (4). Larger the term, higher the market price by shifting up the supply equation.

Solving the following fixed point problem for P_{rt} numerically given parameter values, we obtain the equilibrium price $P^*_{rt}(s_{rt}, D_{rt})$ as a solution of

$$P_{rt} = \gamma_0 + \gamma_1 \frac{\exp(D_{rt}) \cdot (P_{rt})^{\alpha_1}}{S_{rt}} + \underbrace{\tilde{\gamma} 1(t \leq 1983)}_{>0}.$$

Finally, we obtain the equilibrium quantity $Q^*_{rt}(s_{rt}, D_{rt})$ by substituting $P^*_{rt}(s_{rt}, D_{rt})$ into (1).

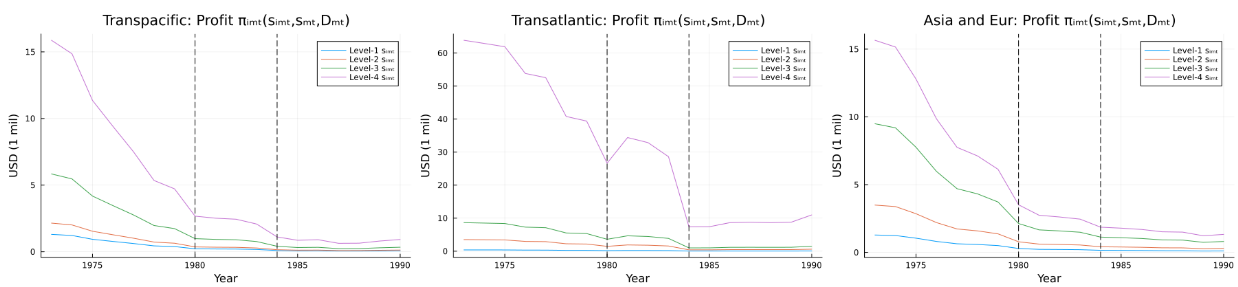
[25] Define $\Delta(P_{rt}) = P_{rt} - \gamma_0 - \gamma_1 \frac{\exp(D_{rt}) \cdot (P_{rt})^{\alpha_1}}{S_{rt}}$ and find the root of $\Delta(P_{rt}) = 0$. Then, $\Delta(P_{rt})$ is an increasing function of P_{rt}, i.e., $\frac{\partial \Delta(P_{rt})}{\partial P_{rt}} = 1 - \gamma_1 \frac{\exp(D_{rt})}{S_{rt}} \alpha_1 (P_{rt})^{\alpha_1 - 1} > 0$ and $\lim_{P_{rt} \to 0} \Delta(P_{rt}) < 0$ where $\alpha_1 < 0, \gamma_0 > 0$, and $\gamma_1 > 0$. So, the solution is unique as the equilibrium price under these standard parameters. Estimated parameters in Section 5 satisfy the condition.

Static profits in market m and route r For the dynamic part, we derive market-year-level variables by aggregating route-year-level ones. Firm i in market m in year t has the static profit defined as follows:

$$
\begin{aligned}
&\pi_{imt}(s_{imt}, s_{mt}, D_{mt}) = \sum_{r \in m} \pi_{irt}(s_{irt}, s_{rt}, D_{rt}), \qquad (5)\\
&\pi_{irt}(s_{irt}, s_{rt}, D_{rt}) = P^*_{rt}(s_{rt}, D_{rt}) q_{irt} - \int_0^{q_{irt}} mc_{irt}(q, s_{irt})) dq,\\
&\text{s.t.} \quad q_{irt} = \begin{cases} Q^*_{rt}(s_{rt}, D_{rt})\omega_{irt} & \text{if } t \leq 1983 \\ \frac{P^*_{rt}(s_{rt}, D_{rt}) - \gamma_0}{\gamma_1} s_{irt} & \text{otherwise} , \end{cases} \qquad \omega_{irt} \in [0,1], \forall i, \sum_{i=1}^{N_{rt}} \omega_{irt} = 1,
\end{aligned}
$$

where ω_{irt} is the service quota within the cartel and $D_{mt} = (D_{rt})_{r \in m}$ contains route-year-level demand states of eastbound and westbound in market m in year t. In the data, shipping conferences impose $\omega_{irt} = s_{irt} / \sum_{i=1}^{N_{rt}} s_{irt}$(= tonnage share) based on *Code of conduct of liner conferences, Article 2*. Note that route-year-level tonnage is equivalent to market-year-level tonnage, that is, $s_{rt} = s_{mt}$ because each ship is operated in both eastbound and westbound routes. Changing the allocation rule on ω_{irt} is insightful in counterfactuals.

Note that firms do not strategically control utilization rates by assumption. Thus, tonnage capacity shares determine the profits directly and the profit is determined only by the states (s_{mt}, D_{mt}) and there is no strategic interaction with q_{irt} in the spot market like Cournot competition.



(a) Transpacific π_{mt} (b) Transatlantic π_{mt} (c) Asia and Eur π_{mt}

Figure 4: Estimated market-year-level prices, quantities, total tonnage, and firm's profit of each level.

Note: Each element is derived from the discretized actual state in the data.

For initial insight, I establish a connection between static profits (5) and tonnage capacities s_{irt} determined by dynamic decisions before delving into the dynamic model's specifics. Figure 4 illustrates estimated profits for various capacity levels, as subsequently introduced, conditioned on actual capacity transitions. Level-1 firms represent minimum capacity firms, while level-4 firms represent maximum capacity firms. Larger capacity firms yield higher profits compared to their smaller counterparts, highlighting the incentive for firms to augment capacities despite incurring substantial sunk investment costs. See more qualitative analysis in Appendix C.2.

3.3 Dynamics

Time horizon Given the static part and industry regime, I introduce a model where time is discrete with $t = 1, 2, \cdots, T$. In this paper, $t = 1$ refers to 1973, i.e., the initial year of the post-Oil-Shock period and $t = T = 18$ refers to 1990, just before the dissolution of the Soviet Union.

Market I model conference markets in which firms follow collusive behaviors determined by shipping conferences in collusive periods before 1984, i.e., $1 \leq t \leq 12$. Non-conference markets, which do not allow cartels, are not included in the model, and the aggregate quantities are exogenously determined outside the model. A market is defined as a round-trip route, which is the unit by which each ship is deployed. Let $m \in \mathcal{M}$ be a conference market, where $\mathcal{M}$ is a set of conference markets, that is, $\mathcal{M} = \{$transpacific, transatlantic, and Asia-Europe$\}$ and $M = |\mathcal{M}| = 3$. We assume that these markets are independent for simplicity.

Player Let $\mathcal{N}_{mt}$ be the set of incumbent firms, and N_{mt} be the number of incumbent firms. Suppose N_{mt} incumbent firms exist as players in market m in year t. Also, let $\mathcal{N}_{mt}^{pe}$ be the set of potential entrants. I assume that four potential entrant firms exist as players across all periods, as is observed in the data, i.e., $|\mathcal{N}_{mt}^{pe}| = 4$.

Action Potential entrant firm $i \in \mathcal{N}_{mt}^{pe}$ chooses action $a_{imt} \in \mathcal{A}^{pe} = \{x, e\}$ where $a_{imt} = x$ means quitting the market, and $a_{imt} = e$ means entering the market. Incumbent firm $i \in \mathcal{N}_{mt}$ also chooses action $a_{imt} \in \mathcal{A}^{inc} = \{x, k, b\}$ where $a_{imt} = x$ means exiting the market, $a_{imt} = k$ means staying in the market without investing, and $a_{imt} = b$ means staying in the market with investment. These actions change the evolution of state variables.

State Let $\tilde{s}_{imt} \in \mathcal{R}+$ be the "actual" tonnage size of the incumbent firm $i \in \mathcal{N}_{mt}$ in market m in year t. For dynamic estimation, discretization of continuous state variables is necessary. Let $\mathcal{S}_{mt}$ be the set of discretized tonnage levels in market m in year t. I assume that the discretization grids are four. Then, $\mathcal{S}_{mt} = \{1, 2, 3, 4\}$. Let $s_{imt} \in \mathcal{S}_{mt}$ be the discretized tonnage level of the incumbent firm $i \in \mathcal{N}_{mt}$ in market m in year t as a capacity level of actual tonnage size $\tilde{s}_{imt}$. Concretely, based on data fitting, s_{imt} is determined by the following discretization formula:

$$s_{imt} = \begin{cases} 1 & \text{if } \tilde{s}_{imt} \leq \exp(8.5) \\ 2 & \text{if } \exp(8.5) < \tilde{s}_{imt} \leq \exp(9.5) \\ 3 & \text{if } \exp(9.5) < \tilde{s}_{imt} \leq \exp(10.5) \\ 4 & \text{if } \exp(10.5) < \tilde{s}_{imt} \end{cases},$$

and we call firm i a level-l firm if $s_{imt} = l$ for convenience. I also assume that the potential entrant $i \in \mathcal{N}_{mt}^{pe}$ has $s_{imt} = 0$ as a null state.[26]

The industry state s_{mt} contains a set of discretized state variables that an individual firm uses to choose an action in market m in year t. We define s_{mt} as follows:

$$s_{mt} = \left(N_{mt}^1, N_{mt}^2, N_{mt}^3, N_{mt}^4\right),$$

where N_{mt}^l represents the number of level-l firms in market m in year t, i.e., $N_{mt}^l = \sum_{i \in \mathcal{N}_{mt}} 1(s_{imt} = l)$. Let $\mathcal{N}_{mt}^l$ be the set of level-l firms for $l = 1, 2, 3$ and 4.

The vector ε_{imt} represents the individual continuous unobserved exogenous state, defined as follows:

$$\varepsilon_{imt} = \begin{cases} (\varepsilon_{imt}^a)_{a \in \mathcal{A}^{inc}}, & \text{if } i \in \mathcal{N}_{mt} \\ (\varepsilon_{imt}^a)_{a \in \mathcal{A}^{pe}}, & \text{if } i \in \mathcal{N}_{mt}^{pe} \end{cases}$$

which is firm i's private information. I assume it is i.i.d. drawn from a type one extreme value distribution.

In summary, firm $i \in \mathcal{N}_{mt} \cup \mathcal{N}_{mt}^{pe}$ knows $(t, s_{imt}, s_{mt}, D_{mt}, \varepsilon_{imt})$, where s_{imt} and s_{mt} are endogenous state variables, D_{mt} is an exogenous demand state variable given by the static model, and ε_{imt} is an exogenous unobserved state variable drawn from a type one extreme value distribution. The researcher observes all the state variables that are common knowledge to firms: s_{imt}, s_{mt}, and D_{mt} for all $i \in \mathcal{N}_{mt} \cup \mathcal{N}_{mt}^{pe}$. The only unobservables for the researcher are the private information shocks ε_{imt} of all $i \in \mathcal{N}_{mt} \cup \mathcal{N}_{mt}^{pe}$.

[26] See Appendix A for details.

State Transition First, the transition rule for s_{imt}, representing the tonnage level of firm $i \in \mathcal{N}_{mt} \cup \mathcal{N}_{mt}^{pe}$ in market m in year t, is defined as follows:

$$s_{imt+1} = \begin{cases} s_{imt} + 1(a_{imt} = b) & \text{if } s_{imt} \in \{1, 2, 3\} \\ s_{imt} & \text{if } s_{imt} = 4 \\ 1(a_{imt} = e) & \text{if } s_{imt} = 0 \end{cases}$$

where $1(\cdot)$ is an indicator function. The second case means that level-4 firms could not increase the level which will be rationalized by the data with the assumption that level-4 firms' choice-specific value function of choosing $a_{imt} = b$ is zero, explained later. The last case means that entering the market implies moving to the lowest state, i.e., $s_{imt+1} = 1$, in the next period.

Second, the transition rule for $(N_{mt}^1, N_{mt}^2, N_{mt}^3, N_{mt}^4)$ is directly determined as follows:

$$\begin{aligned} N_{mt+1}^1 &= N_{mt}^1 + \sum_{i \in \mathcal{N}_{mt}^{pe}} 1(a_{imt} = e) - \sum_{i \in \mathcal{N}_{mt}^1} 1(a_{imt} = b) - \sum_{i \in \mathcal{N}_{mt}^1} 1(a_{imt} = x) \\ N_{mt+1}^2 &= N_{mt}^2 + \sum_{i \in \mathcal{N}_{mt}^1} 1(a_{imt} = b) - \sum_{i \in \mathcal{N}_{mt}^2} 1(a_{imt} = b) - \sum_{i \in \mathcal{N}_{mt}^2} 1(a_{imt} = x) \\ N_{mt+1}^3 &= N_{mt}^3 + \sum_{i \in \mathcal{N}_{mt}^2} 1(a_{imt} = b) - \sum_{i \in \mathcal{N}_{mt}^3} 1(a_{imt} = b) - \sum_{i \in \mathcal{N}_{mt}^3} 1(a_{imt} = x) \\ N_{mt+1}^4 &= N_{mt}^4 + \sum_{i \in \mathcal{N}_{mt}^3} 1(a_{imt} = b) - \sum_{i \in \mathcal{N}_{mt}^4} 1(a_{imt} = x) \end{aligned}$$

Finally, the exogenous demand state transition D_{mt} is not modeled and is equal to the estimated component in the static model. Similarly, the transition of exogenous unobserved state ε_{imt} is determined by the i.i.d. type-one extreme value distribution. These specifications satisfy the *Conditional Independence Assumption* (Rust 1987): conditional on s_{imt}, the realization of s_{imt+1} is independent of ε_{imt}.

Per-period profit Let the per-period profit for incumbent firm $i \in \mathcal{N}_{mt}$ taking action a_{imt} with per-period shock ε_{imt} be:

$$\begin{aligned} \pi_{imt}^d(s_{imt}, s_{mt}, D_{mt}) = \pi_{imt}(s_{imt}, s_{mt}, D_{mt}) - \psi 1(a_{imt} = x) \\ - \phi 1(a_{imt} = k) - (\phi + I(s_{imt}; \iota_1, \iota_2)) 1(a_{imt} = b) + \varepsilon_{imt}^{a_{imt}}, \end{aligned}$$

where $\pi_{imt}(s_{imt}, s_{mt}, D_{mt})$ is the static profit, ψ is the common exit cost, ϕ is the common operation cost, and $I(s_{imt}; \iota_1, \iota_2)$ is the incumbent's investment cost of increasing s_{imt} with parameters ι_1 and ι_2. I normalize the profit to zero when the firm exits, that is, $\pi_{imt}(s_{imt}, s_{mt}, D_{mt}) = 0$. Using the same notation, the per-period profit for potential entrant firm $i \in \mathcal{N}_{mt}^{pe}$ taking action a_{imt} with per-period shock ε_{imt} be

$$\pi_{imt}^{d}(s_{imt}, s_{mt}, D_{mt}) = -\kappa^{e} 1(a_{imt} = e) + \varepsilon_{imt}^{a_{imt}},$$

where κ^e is the potential entrant's entry cost.

Timing All incumbents are deterministically ordered from level-4 firms to level-1 firms. That is, level-4 firms are the first movers, and the potential entrants are the last movers. This is because shipbuilding orders to shipbuilding companies from large operator firms occupy a large amount of their shipbuilding capacity, so these are likely to be accepted earlier than small companies.

For market m in year t, the game timing proceeds as follows:[27]

1. All firms face the current state $(t, s_{imt}, s_{mt}, D_{mt})$ for all $i \in \mathcal{N}_{mt} \cup \mathcal{N}_{mt}^{pe}$,
2. Realize per-period profit $\pi_{imt}^{d}(s_{imt}, s_{mt}, D_{mt})$ for all $i \in \mathcal{N}_{mt}$,
3. Drawing and observing a private i.i.d. shock, ε_{imt}, from a known distribution, all level-4 incumbents $i = 1, \cdots, N_{mt}^4$ simultaneously take discrete action a_{imt} conditional on the state,
4. Drawing and observing a private i.i.d. shock, ε_{imt}, from a known distribution, and observing $a_{i'mt}$ for $i' = 1, \cdots, N_{mt}^4$, all level-3 incumbents $i = N_{mt}^4 + 1, \cdots, N_{mt}^4 + N_{mt}^3$ take discrete action a_{imt} similarly,
5. Drawing and observing a private i.i.d. shock, ε_{imt}, from a known distribution, and observing $a_{i'mt}$ for $i' = 1, \cdots, N_{mt}^4 + N_{mt}^3$, all level-2 incumbents $i = N_{mt}^4 + N_{mt}^3 + 1, \cdots, N_{mt}^4 + N_{mt}^3 + N_{mt}^2$ take discrete action a_{imt} similarly,
6. Drawing and observing a private i.i.d. shock, ε_{imt}, from a known distribution, and observing $a_{i'mt}$ for $i' = 1, \cdots, N_{mt}^4+N_{mt}^3+N_{mt}^2$, all level-1 incumbents $i = N_{mt}^4+N_{mt}^3+N_{mt}^2+1, \cdots, N_{mt}^4+N_{mt}^3+N_{mt}^2+N_{mt}^1$ take discrete action a_{imt} similarly,
7. Drawing and observing a private i.i.d. shock, ε_{imt}, from a known distribution, and observing the actions of all incumbents, potential entrants $i = 1, \cdots, 4$ take discrete action a_{imt} similarly,
8. After observing the actions of all firms, update the state s_{imt} to s_{imt+1} for all $i \in \mathcal{N}_{mt} \cup \mathcal{N}_{mt}^{pe}$.

[27] My model follows Igami (2017). The specified order is deterministic like Igami (2017) and unlike Igami and Uetake (2020) in which the order is stochastic and follows the pattern of month-level-action data. The stochastic alternating move cannot apply to my data because the data on state transition is at the market-year-level, so updating state transition at a shorter time length needs some conversion.

In the last period, each firm receives a terminal value defined as $V_{imT}(s_{mt}, D_{mT}, \varepsilon_{mT}) = (\sum_{\tau=T}^{\infty} \beta^{\tau} \pi_{imT}) = \frac{1}{1-\beta} \pi_{imT}$.

3.3.1 Dynamic optimization problem

Before describing the dynamic optimization problem, I will outline assumptions about the firm's beliefs concerning the evolution of endogenous and exogenous state variables and market regimes, which govern the expectation of future profits.

Belief First, I assume rational expectations regarding firm i's beliefs about rivals' moves, a_{-imt}, where $-i$ denotes i's rivals. This means that firm i correctly expects how its rivals choose dynamic actions up to per-period private shock ε_{-imt}. This setup still allows for dynamic strategic interactions across different-level firms. Second, I assume perfect foresight regarding firm i's beliefs about the evolution of the exogenous demand, D_{mt}, and the market-level marginal cost $\sum_{r \in m} mc_{irt}$ in the per-period profit π^{d}_{imt}. This means that firm i expects the evolution without any uncertainty. Third, I assume that firms perfectly predict the two events in 1980 and 1984 for tractability. This means that all firms know the full history of market regimes from the beginning of the whole period.

Value function The dynamic programming problem for incumbent and entrant firms is defined as follows. I start with level-4 firms. Level-4 firm i's information set consists of industry state $(s_{imt}(=4), s_{mt}, D_{mt}, \varepsilon_{imt})$. Level-4 firm $i \in \mathcal{N}^{4}_{mt}$ also knows the per-period profit $\pi^{d}_{imt}(s_{imt}, s_{mt}, D_{mt})$ for all s_{imt}, s_{mt}, and D_{mt} for all $t = 1, \cdots, T$. Furthermore, Level-4 firm $i \in \mathcal{N}^{4}_{mt}$ knows the functional forms of the operation, exit, entry, and investment costs and the distribution of private shocks, but not their realization. Then, level-4 firm $i \in \mathcal{N}^{4}_{mt}$ forms a belief about the actions of the level-3, level-2, and level-1 firms and potential entrants that have not moved yet.

The value function of level-4 firm $i \in \mathcal{N}^{4}_{mt}$ (i.e., $s_{imt} = 4$) is defined as:

$$
\begin{aligned}
V_{imt}\left(4, s_{mt}, D_{mt}, \varepsilon_{imt}\right) = {} & \pi_{imt}(4, s_{mt}, D_{mt}) \\
& + \max\{\bar{V}^{x}_{imt}\left(4, s_{mt}, \varepsilon^{x}_{imt}\right), \bar{V}^{k}_{imt}\left(4, s_{mt}, \varepsilon^{k}_{imt}\right), \bar{V}^{b}_{imt}\left(4, s_{mt}, \varepsilon^{b}_{imt}\right),
\end{aligned}
$$

and the choice-specific value functions (CSVF) are defined as

$$
\begin{aligned}
\bar{V}_{imt}^{x}\left(4, s_{mt}, \varepsilon_{imt}^{x}\right) &= -\psi + \varepsilon_{imt}^{x}, \\
\bar{V}_{imt}^{k}\left(4, s_{mt}, \varepsilon_{imt}^{k}\right) &= -\phi + \varepsilon_{imt}^{k} \\
&\quad + \beta E\left[V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) \mid 4, s_{mt}, a_{imt} = k, a_{-imt}\right], \\
\bar{V}_{imt}^{b}\left(4, s_{mt}, \varepsilon_{imt}^{b}\right) &= -\phi - I\left(s_{imt}; \iota_1, \iota_2\right) + \varepsilon_{imt}^{b} \\
&\quad + \beta E\left[V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) \mid 4, s_{mt}, a_{imt} = b, a_{-imt}\right],
\end{aligned}
$$

where β is a discount factor and $(\psi, \phi, \iota_1, \iota_2)$ are the parameters for the incumbents. The expectations are over level-4 firm i's belief about the choices of level-1, level-2, and level-3 firms that have not moved in year t yet, and the potential entrants, as well as level-4 firm i's rivals, and the realizations of their private cost shocks. The expectation is derived as follows:

$$
\begin{aligned}
& E\left[V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) \mid 4, s_{mt}, a_{imt} = k, a_{-imt}\right] \\
&= \sum_{s_{imt+1}=1}^{4} \sum_{s_{mt+1} \in \mathcal{S}_{mt}} P(s_{imt+1}, s_{mt+1} | 4, s_{mt}, a_{imt} = k, a_{-imt}) V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) \\
&= \sum_{s_{imt+1}=1}^{4} \sum_{s_{mt+1} \in \mathcal{S}_{mt}} P(s_{imt+1} | 4, s_{mt}, a_{imt} = k) P(s_{mt+1} | s_{mt}, a_{-imt}) V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) \\
&= \sum_{s_{mt+1} \in \mathcal{S}_{mt}} P(s_{mt+1} | s_{mt}, a_{-imt}) V_{imt+1}\left(4, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right),
\end{aligned}
$$

where the second equation is derived from exogenous D_{mt+1} and i.i.d. ε_{imt+1}, the third equation is obtained from the independence of s_{imt+1} and s_{mt+1} in calculation of transitions, and the fourth equation is derived from the transition specification of s_{imt} for level 4 firms, i.e., $P(s_{imt+1}|4, s_{mt}, a_{imt} = k)$ is one if $s_{imt+1} = 4$, zero otherwise. Similarly,

$$
E\left[V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) \mid 4, s_{mt}, a_{imt} = b, a_{-imt}\right]
$$

can be decomposed as $\sum_{s_{mt+1} \in \mathcal{S}_{mt}} P(s_{mt+1}|s_{mt}, a_{-imt}) V_{imt+1}\left(4, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right)$. The decomposition of $P(s_{mt+1}|s_{mt}, a_{-imt})$ is shown in detail after introducing conditional choice probabilities.

Level-4 firm i solves the following problem:

$$\max_{a_{imt}\in\mathcal{A}^{inc}} \pi_{imt}(4, s_{mt}, D_{mt}) + 1(a_{imt}=x)\bar{V}^{x}_{imt}\left(4, s_{mt}, \varepsilon^{x}_{imt}\right)$$
$$+ 1(a_{imt}=k)\bar{V}^{k}_{imt}\left(4, s_{mt}, \varepsilon^{k}_{imt}\right) + 1(a_{imt}=b)\bar{V}^{b}_{imt}\left(4, s_{mt}, \varepsilon^{b}_{imt}\right).$$

Level-4 firm i's best response $a^*_{imt}(4, s_{mt}, \varepsilon_{imt}, (a^*_{i'mt})_{i'\neq i, i'\in\mathcal{N}^4_{mt}})$ is the optimal solution to this optimization problem. However, note that the solution does not need to be conditioned on rivals' actions $(a_{i'mt})_{i'\in\mathcal{N}_{mt}\cup\mathcal{N}^{pe}_{mt}\setminus i}$ because of the rational expectation assumption on rivals' moves and symmetricity. Therefore, the problem is treated as a single-agent problem.

When it is the turn of level-3 firms to move, the information set of level-3 firm i consists of the industry state $(s_{imt}(=3), s_{mt}, D_{mt}, \varepsilon_{imt})$ and the actions of level-4 firms that have already moved. Level-3 firm $i \in \mathcal{N}^3_{mt}$ also knows the per-period profit $\pi^d_{imt}(s_{imt}, s_{mt}, D_{mt})$ for all s_{imt}, s_{mt}, and D_{mt} for all $t = 1, \cdots, T$ and is aware of the functional forms of the operation, exit, entry, and investment costs, and the distribution of private shocks, but not their realizations. Then, I construct the value function of level-3 firms as level-4 firms. Level-3 firm i's best response $a^*_{imt}(3, s_{mt}, \varepsilon_{imt}, (a^*_{i'mt})_{i'\in\mathcal{N}^4_{mt}}, (a^*_{i'mt})_{i'\neq i, i'\in\mathcal{N}^3_{mt}})$ is the optimal solution to this optimization problem.

When it is the turn of level-2 firms to move, the information set of level-2 firm i consists of the industry state $(s_{imt}(=2), s_{mt}, D_{mt}, \varepsilon_{imt})$ and the actions of level-3 and level-4 firms. Level-2 firm $i \in \mathcal{N}^2_{mt}$ also knows the per-period profit $\pi^d_{imt}(s_{imt}, s_{mt}, D_{mt})$ for all s_{imt}, s_{mt}, and D_{mt} for all $t = 1, \cdots, T$ and is aware of the functional forms of the operation, exit, entry, and investment costs, and the distribution of private shocks, but not their realizations. Then, I construct the value function and best response of level-2 firms as level-3 firms.

When it is level-1 firms' turn to move, level-1 firm i's information set consists of industry state $(s_{imt}(= 1), s_{mt}, D_{mt}, \varepsilon_{imt})$ and the actions of level-4, level-3, and level-2 firms. Level-1 firm $i \in \mathcal{N}^1_{mt}$ also knows per-period profit $\pi^d_{imt}(s_{imt}, s_{mt}, D_{mt})$ for all s_{imt}, s_{mt} and D_{mt} for all $t = 1, \cdots, T$ and knows the functional forms of the operation, exit, entry, and investment costs and the distribution of private shocks, but not their realization. Then, I construct the value function and best response of level-1 firms as level-2 and level-3 firms.

Finally, when it is potential entrant firms' turn, potential entrant firm i's information set consists of industry state $(s_{imt}(=0), s_{mt}, D_{mt}, \varepsilon_{imt})$ and the actions of level-4, level-3, level-2, and level-1 firms. Potential entrant firm i also knows per-period profit $\pi^d_{imt}(s_{imt}, s_{mt}, D_{mt})$ for all s_{imt}, s_{mt} and D_{mt} for all $t = 1, \cdots, T$ and knows the functional forms of the operation, exit, entry, and investment costs and the distribution of private shocks, but not their realization.

The value function of potential entrant firm i (i.e., $s_{imt} = 0$) is defined as follows:

$$V_{imt}\left(0, s_{mt}, D_{mt}, \varepsilon_{imt}\right) = \max\{\bar{V}^x_{imt}\left(0, s_{mt}, \varepsilon^x_{imt}\right), \bar{V}^e_{imt}\left(0, s_{mt}, \varepsilon^k_{imt}\right)\},$$

where the expectation is taken over potential entrant firm i's beliefs about the choices of all level firms, as well as those of i's potential entrant rivals, and the realizations of their private cost shocks. The CSVFs are defined as follows:

$$\begin{aligned}
\bar{V}^x_{imt}\left(0, s_{mt}, \varepsilon^x_{imt}\right) &= 0 + \varepsilon^x_{imt} \\
\bar{V}^e_{imt}\left(0, s_{mt}, \varepsilon^e_{imt}\right) &= -\kappa^e + \varepsilon^e_{imt} \\
&\quad + \beta E\left[V_{imt+1}\left(0, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) \mid 0, s_{mt}, a_{imt} = e, a_{-imt}\right].
\end{aligned}$$

Potential entrant firm i solves the following problem:

$$\begin{aligned}
\max_{a_{imt} \in \mathcal{A}^{pe}} &\pi_{imt}(0, s_{mt}, D_{mt}) + 1(a_{imt} = x)\bar{V}^x_{imt}\left(0, s_{mt}, \varepsilon^x_{imt}\right) \\
&+ 1(a_{imt} = e)\bar{V}^e_{imt}\left(0, s_{mt}, \varepsilon^e_{imt}\right),
\end{aligned}$$

and potential entrant firm i's best response $a^*_{imt}(0, s_{mt}, \varepsilon_{imt}, (a^*_{i'mt})_{i' \in \mathcal{N}_{mt} \cup \mathcal{N}^{pe}_{mt} \setminus i})$ is the i's optimal solution to the optimization problem. Under the rational expectation assumption on rivals' moves and symmetricity, the problem is treated as a single-agent problem.

Integrated Value Function The integrated value function of incumbent firm $i \in \mathcal{N}_{mt}$ can be written as

$$\begin{aligned}
&E[V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right) | s_{imt}, s_{mt}, a_{imt}, a_{-imt}] \\
&= \sigma\left[\gamma + \log\left(\exp\left(\frac{\tilde{V}^x_{imt}\left(s_{imt}, s_{mt}, D_{mt}\right)}{\sigma}\right) + \exp\left(\frac{\tilde{V}^k_{imt}\left(s_{imt}, s_{mt}, D_{mt}\right)}{\sigma}\right) + \exp\left(\frac{\tilde{V}^b_{imt}\left(s_{imt}, s_{mt}, D_{mt}\right)}{\sigma}\right)\right)\right],
\end{aligned}$$

where γ is an Euler constant, σ is a logit scale parameter, and $\tilde{V}^a_{imt}(s_{imt}, s_{mt}, D_{mt}) = \bar{V}^a_{imt}\left(s_{imt}, s_{mt}, D_{mt}, \varepsilon^a_{imt}\right) - \varepsilon^a_{imt}$ is the deterministic part of the value function $\bar{V}^a_{imt}$ for all $a \in \mathcal{A}^{inc}$.

Similarly, the integrated value function of potential entrant $i \in \mathcal{N}^{pe}_{mt}$ has the following analytical formula:

$$
\begin{aligned}
&E[V_{imt+1}\left(s_{imt+1}, s_{mt+1}, D_{mt+1}, \varepsilon_{imt+1}\right)|s_{imt}, s_{mt}, a_{imt}, a_{-imt}] \\
&= \sigma\left[\gamma + \log\left(\exp\left(\frac{\tilde{V}^{x}_{imt}\left(s_{imt}, s_{mt}, D_{mt}\right)}{\sigma}\right) + \exp\left(\frac{\tilde{V}^{e}_{imt}\left(s_{imt}, s_{mt}, D_{mt}\right)}{\sigma}\right)\right)\right],
\end{aligned}
$$

where $\tilde{V}^a_{imt}(s_{imt}, s_{mt}, D_{mt}) = \bar{V}^a_{imt}\left(s_{imt}, s_{mt}, D_{mt}, \varepsilon^a_{imt}\right) - \varepsilon^a_{imt}$ is the deterministic part of the value function $\bar{V}^a_{imt}$ for all $a \in \mathcal{A}^{pe}$.

Given these derivations, I can write the expected value functions from terminal period $t = T$ to initial period $t = 1$ and numerically solve these by backward induction. For convenience, I define θ_π as a set of dynamic parameters, i.e., $\theta_\pi = (\psi, \phi, \kappa^e, \iota_1, \iota_2, \sigma)$.

Conditional choice probability If ε_{mt} is drawn i.i.d. from T1EV, the CSVF gives the ex-ante optimal conditional choice probability (CCP) of action $a \in \{x, k, b\}$ of level-l incumbent i (i.e., $s_{imt} = l$) as follows:

$$
Pr^l(a_{imt} = a|s_{imt}, s_{mt}, D_{mt}) = \frac{\exp\left(\frac{\tilde{V}^a_{imt}(s_{imt}, s_{mt}, D_{mt})}{\sigma}\right)}{W_{imt}},
$$

where $W_{imt} = \exp\left(\frac{\tilde{V}^x_{imt}(s_{imt}, s_{mt}, D_{mt})}{\sigma}\right) + \exp\left(\frac{\tilde{V}^k_{imt}(s_{imt}, s_{mt}, D_{mt})}{\sigma}\right) + \exp\left(\frac{\tilde{V}^b_{imt}(s_{imt}, s_{mt}, D_{mt})}{\sigma}\right)$. Note that, given symmetricity, $Pr^l(a_{imt} = a|s_{imt}, s_{mt}, D_{mt}) = Pr^l(a_{i'mt} = a|s_{i'mt}, s_{mt}, D_{mt})$ for $i, i' \in \mathcal{N}^l_{mt}$ so that we also use $Pr^l(a_{lmt} = a|s_{mt}, D_{mt})$ as an expression of CCP of level-l firms.

Potential entrant i (i.e., $s_{imt} = 0$) has an analogous CCP of action $a \in \{x, e\}$:

$$
Pr^{pe}(a_{imt} = a|s_{imt}, s_{mt}, D_{mt}) = \frac{\exp\left(\frac{\tilde{V}^a_{imt}(s_{imt}, s_{mt}, D_{mt})}{\sigma}\right)}{W_{imt}},
$$

where $W_{imt} = \exp\left(\frac{\tilde{V}^x_{imt}(s_{imt}, s_{mt}, D_{mt})}{\sigma}\right) + \exp\left(\frac{\tilde{V}^e_{imt}(s_{imt}, s_{mt}, D_{mt})}{\sigma}\right)$. Given symmetricity, we also use $Pr^l(a_{0mt} = a|s_{mt}, D_{mt})$ as an expression of CCP of potential firms.

Decomposition of $P(s_{mt+1}|s_{mt}, a_{-imt})$ For the decomposition of $P(s_{mt+1}|s_{mt}, a_{-imt})$, let K^l_{mt} be the number of level l firms keep staying at the current level, EX^l_{mt} be the number of level l firms choosing exit, B^l_{mt} be the number of level l firms choosing building ships, and $N^l_{mt} = K^l_{mt} + EX^l_{mt} + B^l_{mt}$ be the number of all level l firms. Also, let EX^{pe}_{mt} be the number of potential entrants choosing exit, E^{pe}_{mt} be the number of potential entrants choosing entry, and $N^{pe}_{mt} = EX^{pe}_{mt} + E^{pe}_{mt}$ be the number of all potential firms. Based on the belief assumption, these determine the transition of s_{mt+1} from s_{mt}. Then, the decomposition is written as follows:

$$
\begin{aligned}
&P(s_{mt+1}|s_{mt}, a_{-imt}) \\
&= \sum_{s_{mt+1}=\Psi\left(N^{pe}_{mt}, EX^{pe}_{mt}, \left(N^l_{mt}, EX^l_{mt}, B^l_{mt}\right)_{l=1,2,3,4}, s_{mt}, a_{-imt}\right)} P(N^{pe}_{mt}, EX^{pe}_{mt}, (N^l_{mt}, EX^l_{mt}, B^l_{mt})_{l=1,2,3,4}|s_{mt}; \theta_\pi), \\
&P(N^{pe}_{mt}, EX^{pe}_{mt}, (N^l_{mt}, EX^l_{mt}, B^l_{mt})_{l=1,2,3,4}|s_{mt}; \theta_\pi) \\
&= \left(P^{pe}(N^{pe}_{mt}, EX^{pe}_{mt} \mid 0, s_{mt}; \theta_\pi) \prod_{l=1}^{4} P^l(N^l_{mt}, EX^l_{mt}, B^l_{mt} \mid l, s_{mt}; \theta_\pi)\right), \\
&P^l(N^l_{mt}, EX^l_{mt}, B^l_{mt} \mid l, s_{mt}; \theta_\pi) \\
&= \begin{pmatrix} N^l_{mt} \\ EX^l_{mt} \end{pmatrix} \begin{pmatrix} N^l_{mt} - EX^l_{mt} \\ B^l_{mt} \end{pmatrix} Pr^l\left(a_{lmt} = x \mid s_{mt}; \theta_\pi\right)^{EX^l_{mt}} \\
&\qquad \times Pr^l\left(a_{lmt} = k \mid s_{mt}; \theta_\pi\right)^{N^l_{mt} - EX^l_{mt} - B^l_{mt}} \times Pr^l\left(a_{lmt} = b \mid s_{mt}; \theta_\pi\right)^{B^l_{mt}}, \\
&P^{pe}(N^{pe}_{mt}, EX^{pe}_{mt} \mid s_{mt}; \theta_\pi) \\
&= \begin{pmatrix} N^{pe}_{mt} \\ EX^{pe}_{mt} \end{pmatrix} Pr^{pe}\left(a_{0mt} = x \mid s_{mt}; \theta_\pi\right)^{EX^{pe}_{mt}} \times Pr^{pe}\left(a_{lmt} = e \mid s_{mt}; \theta_\pi\right)^{N^{pe}_{mt} - EX^{pe}_{mt}},
\end{aligned}
$$

where $Pr^l(\cdot)$ and $Pr^{pe}(\cdot)$ are CCPs of level l firms and potential entrants conditional on dynamic parameters θ_π and rivals' actions up to the current turn, $\begin{pmatrix} n \\ k \end{pmatrix} = \frac{n!}{k!(n-k)!}$, and the operator $\Psi(\cdot)$ produces the list of future states from current states based on transition rules, that is,

$$
\begin{aligned}
\Psi(N^{pe}_{mt}, EX^{pe}_{mt}, (N^l_{mt}, EX^l_{mt}, B^l_{mt})_{l=1,2,3,4}, s_{mt}, a_{-imt}) = (&N^1_{mt+1} = N^1_{mt} - EX^1_{mt} + (N^{pe}_{mt} - EX^{pe}_{mt}), \\
&N^2_{mt+1} = N^2_{mt} - EX^2_{mt} + B^1_{mt}, \\
&N^3_{mt+1} = N^3_{mt} - EX^3_{mt} + B^2_{mt} \\
&N^4_{mt+1} = N^4_{mt} - EX^4_{mt} + B^3_{mt})
\end{aligned}
$$

where a_{-imt} up to the current turn is incorporated in the right hand side. The expression of $P(s_{mt+1}|s_{mt}, a_{-imt})$ captures market-level state transition consistent with data via the symmetric CCP of each level firm. Note that $P(s_{mt+1}|s_{mt}, a_{-imt})$ is updated for each turn of each level firm conditional on a_{-imt} up to the current turn.

3.3.2 Equilibrium concept

I use a finite-horizon, sequential-move dynamic discrete game with private information and use a perfect Bayesian Nash Equilibrium (PBE) in type-symmetric pure strategies as an equilibrium concept proposed by Igami (2017, 2018), and Igami and Uetake (2020). The CCP constitutes the type-symmetric equilibrium strategy under the agents' correct belief. The equilibrium focuses on across-level competition assuming implicitly that there is no within-level competition. The model is equivalent to a single-agent problem (Rust 1987) where the decision timing is in sequential order. At each timing, firms make their dynamic discrete choices to maximize their expected values under rational expectations of the evolution of endogenous state variables and perfect foresight of the evolution of exogenous state variables. The "type" corresponds to discretized state level-s_{imt}. Intuitively, if cartels exist, firms can enjoy higher per-profits and expected future profits so that they want to invest more with collusive fixed prices. Otherwise, firms have low incentives to invest more with competitive prices.

The existence and uniqueness of the equilibrium hold under strong restrictions such that: (i) the game has a finite time horizon; (ii) firms are (ex-ante) homogeneous in their profit functions and transition probabilities; and (iii) at every timing within a year, only one firm can make an investment decision (Aguirregabiria *et al.* 2021). In this paper, restriction (i) is satisfied by specifying terminal period T, and restriction (ii) is satisfied because private information ε_{imt} is drawn i.i.d. from the type one extreme value distribution and the same level firms are homogenous. The firm's payoff is affected by its rivals' cost shocks only through their actual choices and not by the specific realizations of ε^{a}_{-imt} for all $a \in \mathcal{A}^{inc} \cup \mathcal{A}^{pe}$. Restriction (iii) is also satisfied because different types of firms move sequentially after observing the dynamic choices of earlier movers. At its turn, only the same type of firms with symmetric strategies solve a single-agent problem based on their expectation over the subsequent evolution of endogenous state variables.

3.3.3 Technical specifications

I summarize the technical issues for fine-tuning the model. First, I specify incumbent's investment cost of increasing s_{imt} by one unit, $I\left(s_{\mathrm{imt}}\,; \iota_1, \iota_2\right)$, as

$$I\left(s_{imt}; \iota_1, \iota_2\right) = \begin{cases} \iota_1 & \text{if } s_{imt} = 1, 2 \\ \iota_2 & \text{otherwise.} \end{cases}$$

Second, I fix the discount factor $\beta = 0.9$ which is a standard value. Third, I assume that level-4 firms' CSVF of choosing building ships is zero, that is, $\bar{V}^{b}_{imt}\left(4, s_{mt}, \varepsilon^{b}_{imt}\right)$, to rationalize the fact that level-4 firms do not choose to increase the level.

4 Identification and Estimation

4.1 Demand parameters

Taking the log of demand equation (1), I estimate the parameters $\alpha = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_r)$ from:

$$\log(Q_{rt}) = \alpha_1 \log P_{rt} + \alpha_2 X_{rt} + \alpha_3 1(t \leq 1979) + \alpha_4 1(1980 \leq t \leq 1983) + \alpha_r + \zeta_{rt}, \tag{6}$$

and demand state is defined as $D_{rt} = \alpha_2 X_{rt} + \alpha_3 1(t \leq 1979) + \alpha_4 1(1980 \leq t \leq 1983) + \alpha_r$. However, route-year-level price P_{rt} is correlated with ζ_{rt}. To account for price endogeneity, I estimate (6) using instrumental variables (IVs). The price is instrumented with the average age of ships deployed in each route and the tonnage share of 20-year-old ships. Both are used to capture the fact that old ships are less efficient than new ones to use fuel energy, but both are uncorrelated with unobserved demand factors. The log GDP for the destination area is used as a demand shifter X_{rt}. I add route fixed effects and regime dummies to control route-regime level unobserved heterogeneity. Note that including the regime dummies does not mean the existence of cartel effects on the demand side, but captures some coarse level of time trends. I keep a consistency of regimes on demand and supply sides. I cluster the standard errors at the route level.

The demand parameters are identified from the time-series and cross-sectional variations across the main six routes under constant elasticity functional form. Since ships have to go back and forth between the two areas, two routes serving the same areas have the same level of supply while facing different demand shocks, which helps the identification of the demand parameters.

4.2 Cost parameters

Based on supply equation (4), I estimate $\gamma = (\gamma_1, \gamma_2, \tilde{\gamma}_1, \tilde{\gamma}_2, \gamma_r)$ using IVs:

$$P_{rt} = \gamma_1 \frac{Q_{rt}}{S_{rt}} + \gamma_2 Y_{rt} + \tilde{\gamma}_1 1(t \leq 1979) + \tilde{\gamma}_2 1(1980 \leq t \leq 1983) + \gamma_r + \eta_{irt}, \tag{7}$$

where γ_1 is a route-year-level supply slope, γ_2 is coefficients of cost shifters, $\tilde{\gamma}_1$ and $\tilde{\gamma}_2$ are the cartel effects, γ_r is a route fixed effect, and η_{irt} is an i.i.d. error term. Route marginal cost is defined as $MC_{rt} = \gamma_1 \frac{Q_{rt}}{S_{rt}} + \gamma_r$. Cost shifters Y_{rt} include the average age of ships deployed in each route, the tonnage share of 20-year-old ships, and the average size of ships deployed in each route. These are used to capture the fact that old ships are less efficient than new ones to use fuel energy and larger ships have smaller marginal shipping costs on average. The term $\frac{Q_{rt}}{S_{rt}}$ is instrumented with a demand shifter, log GDP of the destination area, which is excluded from the supply equation.

The cost parameters are identified by the time-series and cross-sectional variations across the main six routes under the functional form assumption and known regime changes from institutional background discussed in Section 2.

4.3 Dynamic parameters

We estimate dynamic parameters, θ_π, by Maximum Likelihood Estimation (MLE). Let K^l_{mt} be the number of level l firms staying at the current level, EX^l_{mt} be the number of level l firms choosing exit, B^l_{mt} be the number of level l firms choosing building ships, and $N^l_{mt} = K^l_{mt} + EX^l_{mt} + B^l_{mt}$ be the number of all level l firms. Also, let EX^{pe}_{mt} be the number of potential entrants choosing exit, E^{pe}_{mt} be the number of potential entrants choosing entry, and $N^{pe}_{mt} = EX^{pe}_{mt} + E^{pe}_{mt}$ be the number of all potential firms. Then, the joint likelihood for observing $(N^l_{mt}, EX^l_{mt}, B^l_{mt})$ in year t in market m is

$$\begin{aligned}
P^l(N^l_{mt}, EX^l_{mt}, B^l_{mt} \mid s_{mt}, D_{mt}; \theta_\pi) = &\begin{pmatrix} N^l_{mt} \\ EX^l_{mt} \end{pmatrix} \begin{pmatrix} N^l_{mt} - EX^l_{mt} \\ B^l_{mt} \end{pmatrix} Pr^l\left(a_{lmt} = x \mid s_{mt}, D_{mt}; \theta_\pi\right)^{EX^l_{mt}} \\
&\times Pr^l\left(a_{lmt} = k \mid s_{mt}, D_{mt}; \theta_\pi\right)^{N^l_{mt} - EX^l_{mt} - B^l_{mt}} \\
&\times Pr^l\left(a_{lmt} = b \mid s_{mt}, D_{mt}; \theta_\pi\right)^{B^l_{mt}},
\end{aligned}$$

and the joint likelihood for observing $(N^{pe}_{mt}, EX^{pe}_{mt})$ in year t in market m is

$$\begin{aligned}
P^{pe}(N^{pe}_{mt}, EX^{pe}_{mt} \mid s_{mt}, D_{mt}; \theta_\pi) = &\begin{pmatrix} N^{pe}_{mt} \\ EX^{pe}_{mt} \end{pmatrix} Pr^{pe}\left(a_{0mt} = x \mid s_{mt}, D_{mt}; \theta_\pi\right)^{EX^{pe}_{mt}} \\
&\times Pr^{pe}\left(a_{0mt} = e \mid s_{mt}, D_{mt}; \theta_\pi\right)^{N^{pe}_{mt} - EX^{pe}_{mt}}.
\end{aligned}$$

Let $N^{all}_{mt} = (N^l_{mt})_{l=1\cdots4,pe}$, $EX^{all}_{mt} = (EX^l_{mt})_{l=1\cdots4,pe}$ and $B^{all}_{mt} = (B^l_{mt})_{l=1\cdots4}$. Then, the joint log-likelihood for observing $(N^{all}_{mt}, EX^{all}_{mt}, B^{all}_{mt})$ in year $t = 1, \cdots, T$ in market m is defined as:

$$ll_m(\theta_\pi) = \sum_{t=1}^{T} \left(\log \left(P^{pe}(N^{pe}_{mt}, EX^{pe}_{mt} \mid s_{mt}, D_{mt}; \theta_\pi) \prod_{l=1}^{4} P^l(N^l_{mt}, EX^l_{mt}, B^l_{mt} \mid s_{mt}, D_{mt}; \theta_\pi) \right) \right).$$

The dynamic parameters are identified by the observed entry/exit/investment choices in the panel data of global container shipping firms, together with estimated static parameters. For example, a large investment cost decreases the predicted CCP of investing and increases the predicted CCP of staying at the same level. I estimate θ_π by the full solution method known as Nested Fixed Point Algorithm (NFP) proposed by Rust (1987) in which the outer loop is MLE to find maximizers of the joint likelihood and the inner loop solves the finite horizon problem for each set of candidate parameters. At the equilibrium, fixed points of CCPs generate corresponding value functions. I apply the algorithm of Igami (2017) and Kasahara and Shimotsu (2012). See the computation detail in Appendix A. I estimate the parameters for each market separately because of computational simplicity and data fitting capturing market-level heterogeneity.

5 Estimation results

5.1 Demand for container shipping

Table 4: Estimation results of static parameters.

(a) Demand

	1st ($\log(P_{rt})$)	2nd ($\log(Q_{rt})$)
$\log(P_{rt})$		-0.869**
		(0.308)
log GDP: $\log(X_{rt})$	0.427*	0.434*
	(0.161)	(0.197)
$1(t \leq 1979)$	0.361*	0.396*
	(0.110)	(0.153)
$1(1980 \leq t \leq 1983)$	0.082	0.095+
	(0.070)	(0.052)
Avg ship age:	-0.151**	
	(0.023)	
Share (20+ y.o. ships)	3.187*	
	(1.217)	
Route FE	X	X
R2	0.862	0.860
R2 Adj.	0.847	0.847

(b) Supply

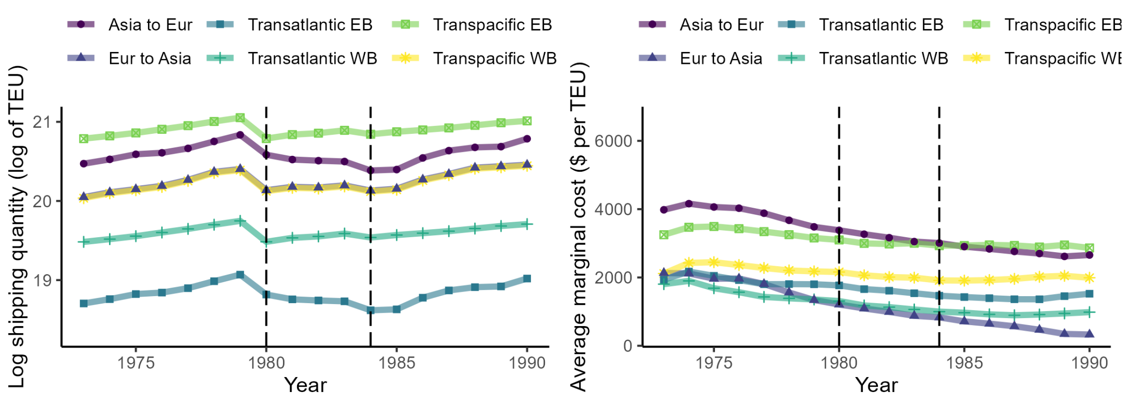
	1st ($\frac{Q_{rt}}{s_{rt}}$)	2nd (P_{rt})
Q_{rt}/S_{rt}		180.190+
		(108.322)
Avg ship age	-0.808*	-146.641
	(0.298)	(101.551)
Avg ship size	-6.688	1332.402+
	(3.653)	(787.465)
Share (20+ y.o. ships)	34.360	4259.866
	(24.333)	(6611.957)
$1(t \leq 1979)$	-0.577	1106.208**
	(0.430)	(362.205)
$1(1980 \leq t \leq 1983)$	-1.521**	440.663**
	(0.355)	(148.448)
log GDP: $\log(X_{rt})$	2.766+	
	(1.088)	
Route FE	X	X
R2	0.341	0.663
R2 Adj.	0.278	0.630

Note: Sample size is 108, i.e., six routes in 1973-1990. The numbers in parentheses show the standard errors, which are clustered at the route level. Significance levels are denoted by $+p < 0.1, {}^{*}p < 0.05, {}^{**}p < 0.01, {}^{***}p < 0.001$.

Table 4 (a) reports the demand estimates. The first column shows the first stage regression. The coefficient of the average ship age is negative. The negative sign captures that shipping services via old ships are provided at a lower price due to the inconvenience caused by service frequency and speed. The coefficient of the share of 20-year-old ships is positive and statistically significant, which means that old ships are worse than young ones in terms of cost efficiency. The second column reports the second-stage results. I find that the estimated price coefficient is -0.869 which is statistically significant. When the shipping price increases by 10%, the shipping quantity decreases by 8.69%. The demand is inelastic and below the lower bound found in the literature. It captures the unique features of containerized transportation, which has no viable cheap alternative to carry general cargo in this period.[28] Figure 5 (a) illustrates route-year-level demand transition. The demand gradually increased in the 1970s and was stationary in the 1980s.

5.2 Cost parameters and cartel effects

Table 4 (b) reports the cost estimates. The first column shows the first stage regression. The coefficient of the average ship age is negative and statistically significant. This implies that markets with older ships provide a smaller amount of shipping service given the route-year-level aggregate tonnage size fixed. The second column reports the second-stage results. I find that the supply equation is increasing in $\frac{Q_{rt}}{S_{rt}}$. Given route-year-level aggregate tonnage size S_{rt} fixed, increasing route-year-level shipping service Q_{rt} by S_{rt} results in a \$180 price increase. Also, cartel effects increased the price from route marginal cost by \$ 1,106 before 1979 and \$ 440 in 1980-1983. The impact on prices is significant. For example, cartel effects increased prices by roughly 20 % in the Asia-to-Europe routes before 1979, and by roughly 50% in the transatlantic westbound route. Figure 5 (b) illustrates route-year-level route marginal cost transition. I find that the route marginal cost decreased gradually. See data fitting in Appendix D.

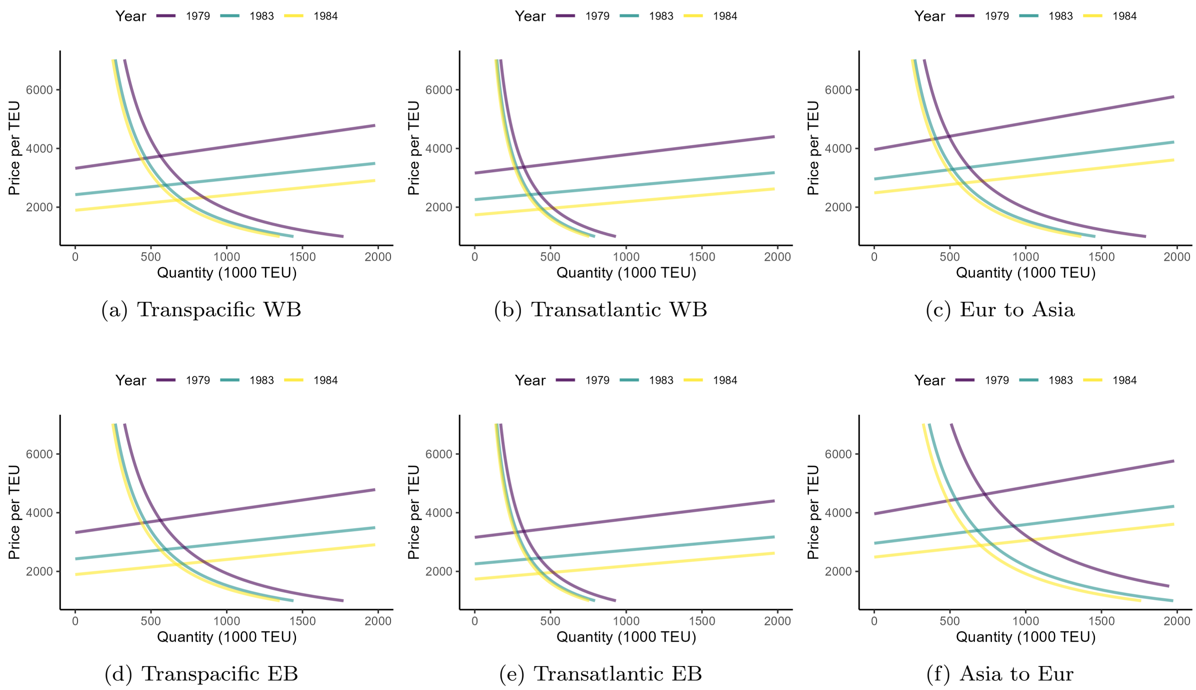


(a) Demand state D_{rt} (b) Route marginal cost MC_{rt}

Figure 5: Estimated demand state and route marginal cost.

Given the estimated route-year-level primitives, Figure 6 provides an intuitive illustration of estimated demand and supply equations in 1979, 1983, and 1984 which correspond to the regimes. The intersection determines the equilibrium prices and quantities. In all markets, equilibrium prices decrease from the collusive regime in 1979 to the competitive regime in 1984 mainly because of the absence of cartel effects in the supply equation. The demand equations also slightly decrease from the collusive regime to the competitive

[28]For example, the price coefficient is -1.03 in dry bulk shipping markets (Brancaccio *et al.* 2020) and -3.89 in recent container shipping markets (Jeon 2022). Also, note that although the low elasticity seems to motivate shipping conferences to increase prices to infinity, this theoretical reasoning is incorrect because consumers can use the non-conference firms.



(a) Transpacific WB (b) Transatlantic WB (c) Eur to Asia

(d) Transpacific EB (e) Transatlantic EB (f) Asia to Eur

Figure 6: Estimated demand and supply equations

Note: The downward-sloping lines are given by the estimated demand equation. The upward-sloping lines are given by the estimated supply equation.

regime. This might be due to the growing demand for noncartel shipping out of my model. From these components, I compute market-year-level equilibrium prices, quantities, total tonnage, and profits through discretization.

5.3 Dynamic parameters

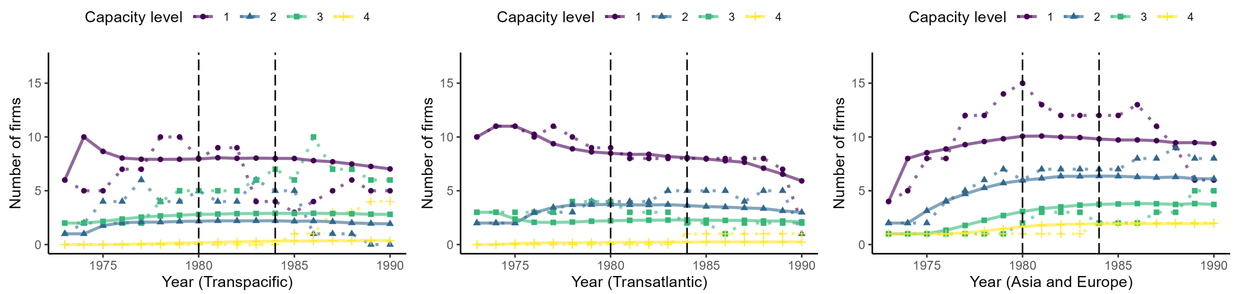
Table 5 displays the results of the dynamic parameters for each market. The estimated dynamic parameters exhibit heterogeneity across markets. For example, in the transatlantic market, the estimated entry cost (κ^e) is \$10.9 billion, while the sign of the estimated entry cost is ambiguous for the Asia-Europe market. This captures the observed pattern of a higher number of entrants in the Asia-Europe markets with low entry costs compared to the other markets. Furthermore, the estimated exit cost (ψ) exceeds the estimated entry cost, which rationalizes the small number of exiting firms observed in the 1980s. The estimated operation cost (ϕ) is \$10.3 billion in the transpacific market, \$9.6 billion in the transatlantic market, and \$10.5 billion in the Asia-Europe market, indicating the homogeneity of the operation costs across markets. This indicates the homogeneity of shipping services in the industry as well as the estimated logit scale parameter (σ). Regarding investment costs of level-1 and level-2 firms (ι_1), the estimates are \$15.2 billion in the transpacific market, \$14.6 billion in the transatlantic market, and \$7.6 billion in the Asia-Europe market. Investment costs of level-3 firms (ι_2) are higher than those of level-1 and -2 firms. Although direct comparison is difficult due to the different data and definitions of investment actions, the estimated values of the sunk costs are higher than previous studies on a global HDD industry (Igami 2017) (\$2-3 billion). This reflects the unique feature of the large sunk costs of shipbuilding and collusive pricing in the early stage of the industry.

Figure 7 illustrates the actual and estimated state transition patterns. The estimated transition represents the mean of equilibrium paths in 1,000 simulations based on CCPs and estimated parameters. The figure suggests that the estimated model reasonably fits the data, albeit in a smoother manner. The analysis reveals several key findings. First, the number of level-1 firms increases in the initial periods and stabilizes in the 1980s. This indicates that collusive pricing before 1980 encouraged firm entry. Second, the number of level-2 firms increases monotonically in the 1970s. Third, the number of level-3 firms gradually increases in the transpacific and Asia-Europe markets but decreases in the transatlantic market. These findings not only explain the different patterns of shipbuilding between the transpacific and transatlantic markets but also suggest that collusive pricing before 1980 incentivized firms to invest in shipbuilding. Finally, the number of level-4 firms reaches approximately one to two, but the estimated path failed to capture the spike only after 1985 in the transpacific market. Although the estimated model does not precisely replicate all the peaks and fluctuations observed in the data, it provides a simple benchmark for comparing actual and counterfactual scenarios in the next section.

Table 5: Dynamic parameters

Parameter	Transpacific	Transatlantic	Asia-Eur
Entry cost: κ^e	0.055	0.109	0.001
	[0.010,0.060]	[0.020,0.109]	[-0.021,0.001]
Exit cost: ψ	0.200	0.193	0.302
	[0.200,0.201]	[0.193,0.200]	[0.302,0.310]
Operation cost: ϕ	0.103	0.096	0.105
	[0.103,0.104]	[0.096,0.097]	[0.105,0.106]
Investment cost: ι_1	0.152	0.146	0.076
	[0.152,0.162]	[0.146,0.210]	[0.076,0.080]
Investment cost: ι_2	0.162	0.256	0.078
	[0.162,0.167]	[0.256,0.800]	[0.078,0.080]
Logit scale: σ	0.101	0.100	0.078
	[0.080,0.152]	[0.090,0.105]	[0.063,0.093]
Log Likelihood	-168.338	-153.593	-158.643

Note: Each market aggregates its eastbound and westbound routes. The 90 percent confidence intervals are in brackets. These intervals are based on likelihood ratio tests (i.e., by comparing $LL(\hat{\theta}_\pi) - LL(\tilde{\theta}_\pi)$ with the corresponding critical values from the χ^2 distribution, where $LL(\theta_\pi)$ is the joint log likelihood evaluated at a vector of parameter values θ_π; $\hat{\theta}_\pi$ and $\tilde{\theta}_\pi$ represent the MLE and its perturbed counterpart, respectively). Thus, the confidence intervals need not be symmetric like Wald-type ones. Each value is measured by 100 billion USD.



(a) Transpacific (b) Transatlantic (c) Asia and Eur

Figure 7: State transition: Estimated (solid) and data (dotted).

Table 6: Welfare evaluation (benchmark)

(a) Transpacific

Regime	CS	PS	SW
1973-1979	2.12	0.10	2.22
1980-1983	0.64	0.02	0.66
1984-1990	0.67	0.01	0.68

(b) Transatlantic

Regime	CS	PS	SW
1973-1979	15.63	0.19	15.82
1980-1983	4.76	0.04	4.80
1984-1990	5.17	0.04	5.21

(c) Asia-Europe

Regime	CS	PS	SW
1973-1979	11.80	0.17	11.97
1980-1983	3.54	0.02	3.56
1984-1990	3.73	0.02	3.75

Note: Each number is the sum of discounted present values at 1973 for each regime. Each value is measured by 1 billion USD.

Table 6 displays regime-market-level measures of consumer surplus (CS), producer surplus (PS), and social welfare (SW) by summing up the present value of each measure for each regime. The table highlights the following key findings. First, market heterogeneity is evident in each welfare measure, with the transpacific market exhibiting smaller CS and PS compared to the other two markets. Smaller PS in the transpacific market is due to the large marginal cost shown in Figure 5 (b). Second, PS represents less than 5% of CS, primarily due to the limited number of level-4 firms generating substantial profits before 1990. However, there is a significant increase in the number of level-4 firms after my data period, aligning with industry history. Third, during the first collusive regime (1973-1979), the observed surplus is about three times larger than that of the subsequent competitive regime (1984-1990). Notably, PS experiences a substantial reduction, reaching only 10 to 25% following the breakdown of the cartel. In contrast, the second collusive regime (1980-1983) demonstrates a surplus similar to the competitive regime, indicating that a welfare-related container crisis mainly occurred around 1980, just before the actual cartel breakdown.

6 Counterfactual

I evaluate the welfare performance of policies concerning cartel effects and inner allocation by conducting counterfactual simulations. Specifically, how the cartel effects and inner allocation mechanism would affect entry, exit, and shipbuilding through shifting the static profit function. I aim to address two main questions. First, if historical shipping cartels were not permitted, how would the market configuration in the industry have evolved? Second, would different inner allocation rules have incentivized the entry of small firms or the shipbuilding of large firms? To assess welfare implications, I compare the gaps observed in the estimated baseline model with those obtained from a counterfactual simulation.

6.1 With and without shipping cartels

The long-run effect of cartels is a fundamental question in empirical studies. In a first counterfactual simulation, I hypothetically eliminate the cartel effect in the profit function and assume that individual service supply is determined by Equation (3) in the whole period. The counterfactual of zero cartel effects is similar to Kalouptsidi (2017) in which the Chinese shipbuilding industry would not receive any subsidy in the counterfactuals. For this counterfactual scenario, I solve the model for a new equilibrium under zero cartel effects (i.e., $\tilde{\gamma}_1 = \tilde{\gamma}_2 = 0$) and use the equilibrium choice probabilities to run 1,000 simulations of the equilibrium path for each level firm in each market.

Table 7 presents state transition patterns of the benchmark model and a counterfactual model without cartel effects. Cartel effects increase the entry and investment of firms in transpacific and transatlantic markets by at most 0.5 firm units for all level firms. Although the effects on a dynamic decision seem small relative to the dynamic sunk costs, the economic impacts are not negligible because the change of market configuration for all level firms significantly affects firms' profits. Cartel effects are small in the Asia-Europe market because the effect is small relative to the average marginal cost and profit rather than in other markets. This suggests the market heterogeneity of the impact of cartels.

Table 8 presents a comparison of welfare measures between the benchmark model and a counterfactual model without cartel effects. Several key findings emerge from this analysis. First, in the counterfactual scenario, PS is reduced by 50% (transpacific), 32% (transatlantic), and 29% (Asia-Europe) compared to the benchmark model between 1973 and 1979. Second, the counterfactual non-cartel scenario results in a 1-3% increase in CS. Although this increase is small, it is reasonable and intuitive when considering the dynamic implications, the supply equation including shipping capacity information, and the quite low demand elasticity. In other words, smaller profits discourage firms' entry and shipbuilding investment, leading to a decrease in the total shipping capacity, and shifting up the supply equation while simultaneously shifting down the curve by the level of cartel effects. Notably, the most significant result is that the prohibition of cartels would not result in an increase in social welfare before 1984 in all markets, i.e., would not be always beneficial. This finding provides empirical support for industry policies involving centralized mechanisms for price and quantity control during the early stages of a new homogenous goods industry, although the impact may not be large economically and may be heterogeneous. Overall, the counterfactual analysis highlights the impact of cartel effects on welfare measures and underscores the dynamic considerations, necessary to understand the observed results, which is also suggested by Fershtman and Pakes (2000) numerically.

Table 7: State transition: Benchmark (point) and non-cartel (dashed)

(a) Transpacific (b) Transatlantic (c) Asia-Europe

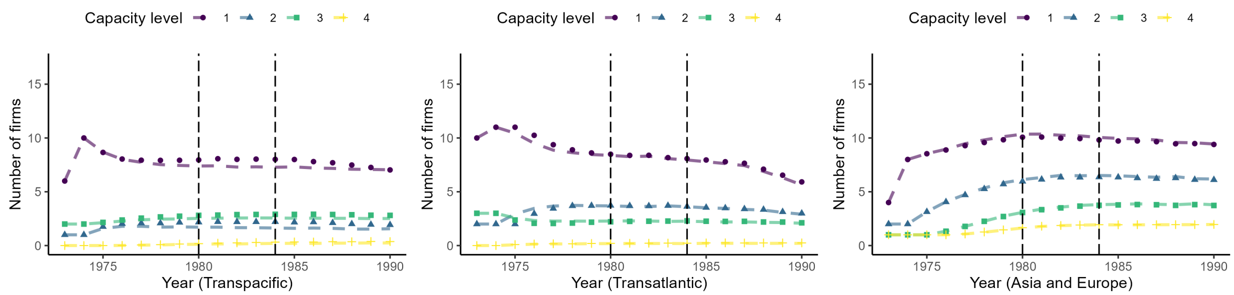


Table 8: Welfare evaluation (non-cartel scenario)

(a) Transpacific

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	2.19	0.05	2.24	(0.03)	(-0.50)	(0.01)
1980-1983	0.64	0.01	0.65	(0.00)	(-0.50)	(-0.02)
1984-1990	0.67	0.01	0.68	(0.00)	(0.00)	(0.00)

(b) Transatlantic

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	15.97	0.13	16.10	(0.02)	(-0.32)	(0.02)
1980-1983	4.80	0.04	4.84	(0.01)	(0.00)	(0.01)
1984-1990	5.16	0.04	5.20	(0.00)	(0.00)	(0.00)

(c) Asia-Europe

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	12.05	0.12	12.17	(0.02)	(-0.29)	(0.02)
1980-1983	3.58	0.02	3.60	(0.01)	(0.00)	(0.01)
1984-1990	3.73	0.02	3.75	(0.00)	(0.00)	(0.00)

Note: Each number is the sum of discounted present values at 1973 for each regime. Each value is measured by 1 billion USD. The number in a bracket shows the proportional change from the benchmark model. For example, (-0.50) means that the hypothetical welfare is $(1 - 0.50) \times 100 = 50\%$ of the actual welfare.

6.2 Under different inner allocation rule

"Market Share Division" within the cartels matters to function cartels (Marshall and Marx 2014). However, to the best of my knowledge, there is a lack of research quantifying the effect of "Market Share Division" on welfare in both the short-run and long-run, primarily due to the unavailability of observed inner allocation rules in typical data. The case of shipping conferences serves as an excellent example, as the inner allocation rule is known and straightforward, as shown in ω_{imt} in Equation (5). This feature allows us to treat the decision to join or leave explicit cartels as a simple choice of entry and exit in cartel markets. Furthermore, the inner allocation mechanism employed by shipping conferences is linked to industry subsidies for specific firms, which are operated under the constraints of government budgets. Subsidy policies on static profits under the constraints are more interpretable than subsidies on lump-sum entry cost, for example, examined by Fan and Xiao (2015). It also may be worthwhile to numerically investigate the optimal inner allocation mechanism for social welfare through analysis of entry, exit, and shipbuilding investment because answering this question theoretically is challenging, as it involves the complex and dynamic strategic decisions of firms.

To highlight the role of the inner allocation rule, I change ω_{irt} to the following rule ω^1_{irt}:

$$\omega^1_{irt} = \tilde{s}_{irt} / \sum_{i=1}^{N_{rt}} \tilde{s}_{irt},$$
$$\tilde{s}_{irt} = \begin{cases} 1.25 \cdot s_{irt} & \text{if } s_{irt} = 1,2 \\ 0.75 \cdot s_{irt} & \text{otherwise} \end{cases} .$$

The rule has the same role of encouraging entry and investment of level-1 and level-2 firms as a subsidy for small firms under some budget constraints. This rule shares the same spirit as the policies encouraging the entry of small firms, discussed in the literature of auction (Krasnokutskaya and Seim 2011) and dynamic entry (Fan and Xiao 2015).[29]

Second, I consider the policy of supporting large incumbent firms. I change ω_{irt} to the following rule ω^2_{irt}:

$$\omega^2_{irt} = \tilde{s}_{irt} / \sum_{i=1}^{N_{rt}} \tilde{s}_{irt},$$
$$\tilde{s}_{irt} = \begin{cases} 1.25 \cdot s_{irt} & \text{if } s_{irt} = 3,4 \\ 0.75 \cdot s_{irt} & \text{otherwise} \end{cases} .$$

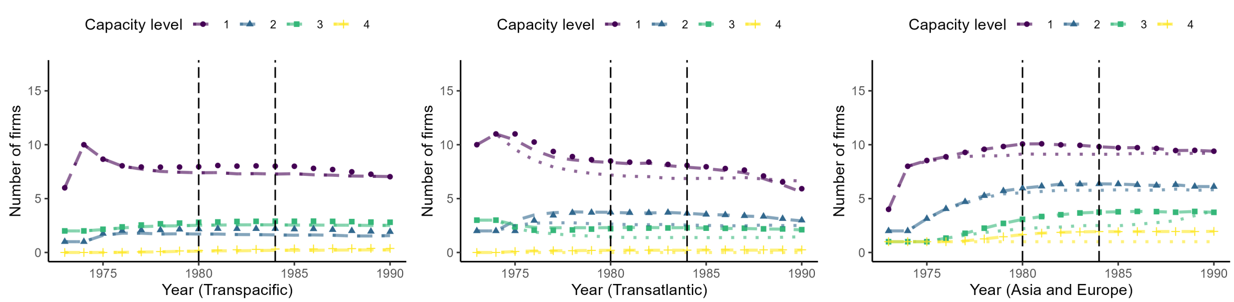
[29] Fan and Xiao (2015) consider the direct subsidy on dynamic entry costs for small potential entrant firms, although the subsidies imposed by the 1996 Telecommunications Act are implicit and thus difficult to quantify.

Figure 9 presents state transition patterns of the benchmark model and a counterfactual model under counterfactual inner allocation rules ω^1_{irt} and ω^2_{irt}. As a remarkable finding, both counterfactual rules reduce entry and investment. Under the allocation rule ω^1_{irt}, level-1 and -2 firms would receive larger profits but have smaller incentives for investment and smaller expected future profits. Under the allocation rule ω^2_{irt}, level-1 and -2 firms would receive smaller profits but have larger incentives for investment and larger expected future profits. These conflicting benefits balance each other and reduce entry.

Table 10 presents the results. First, CS is almost invariant to the change of the inner allocation rule to ω^1_{irt} because the total supply of shipping and the number of entry and exit would be almost invariant. However, the change of the inner allocation rule to ω^2_{irt} would slightly decrease CS in the transatlantic and Asia-Europe markets. Second, the allocation rule ω^1_{irt} encouraging small firms would reduce PS by 6-25 %, whereas the allocation rule ω^2_{irt} encouraging large firms would increase PS by 16-50 % but decreases SW by 1-2%. This concludes that an inner allocation rule encouraging large firms would worsen social welfare for some markets. Third, the transpacific market is invariant to the counterfactual rules, which implies market heterogeneity of the impact of the inner allocation rule. In conclusion, an actual inner allocation rule based on the tonnage share seems the best to maximize social welfare.

Table 9: State transition: Benchmark (point) and ω^1_{irt} (dashed) and ω^2_{irt} (dotted)

(a) Transpacific (b) Transatlantic (c) Asia-Europe



7 Conclusion

I investigate how explicit cartels, known as "shipping conferences" in a global container shipping market facilitated the formation of one of the largest globally integrated markets through the entry, exit, and shipbuilding investment of shipping firms. Using a novel data, I develop and construct a structural model and find that the cartels shifted shipping prices by 20-50% and encouraged firms' entry and investment. In my counterfactual simulation, I compare welfare outcomes with and without the cartels and other inner

Table 10: Welfare evaluation (counterfactual allocation rule)

(a) Transpacific (encouraging small firms)

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	2.12	0.10	2.22	(0.00)	(0.00)	(0.00)
1980-1983	0.64	0.02	0.66	(0.00)	(0.00)	(0.00)
1984-1990	0.67	0.01	0.68	(0.00)	(0.00)	(0.00)

(b) Transpacific (encouraging large firms)

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	2.12	0.10	2.22	(0.00)	(0.00)	(0.00)
1980-1983	0.64	0.02	0.66	(0.00)	(0.00)	(0.00)
1984-1990	0.67	0.01	0.68	(0.00)	(0.00)	(0.00)

(c) Transatlantic (encouraging small firms)

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	15.65	0.17	15.82	(0.00)	(-0.11)	(0.00)
1980-1983	4.76	0.04	4.80	(0.00)	(0.00)	(0.00)
1984-1990	5.16	0.03	5.19	(0.00)	(-0.25)	(0.00)

(d) Transatlantic (encouraging large firms)

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	15.54	0.22	15.76	(-0.01)	(0.16)	(0.00)
1980-1983	4.67	0.05	4.72	(-0.02)	(0.25)	(-0.02)
1984-1990	5.06	0.05	5.11	(-0.02)	(0.25)	(-0.02)

(e) Asia-Europe (encouraging small firms)

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	11.80	0.16	11.96	(0.00)	(-0.06)	(0.00)
1980-1983	3.54	0.02	3.56	(0.00)	(0.00)	(0.00)
1984-1990	3.73	0.02	3.75	(0.00)	(0.00)	(0.00)

(f) Asia-Europe (encouraging large firms)

Regime	CS	PS	SW	CS change	PS change	SW change
1973-1979	11.79	0.18	11.97	(0.00)	(0.06)	(0.00)
1980-1983	3.53	0.03	3.56	(0.00)	(0.50)	(0.00)
1984-1990	3.71	0.02	3.73	(-0.01)	(0.00)	(-0.01)

Note: Each number is the sum of discounted present values at 1973 for each regime. Each value is measured by 1 billion USD. The number in a bracket shows the proportional change from the benchmark model. For example, (-0.50) means that the hypothetical welfare is $(1 - 0.50) \times 100 = 50\%$ of the actual welfare.

allocation rules. I find that cartels significantly increase producer surplus, slightly decrease consumer surplus, and then may increase social welfare by encouraging firms' entry and shipbuilding investment, validating industry policies controlling prices and quantities in the early stage of the new industry, which may not be always harmful. Investigating hypothetical allocation rules supporting large or small firms, I find that the actual rule based on tonnage shares is the best to maximize social welfare.

A logical next step is to investigate the theoretical and numerical properties of the equilibrium concept proposed by Igami (2017, 2018). This specific sequential game focuses on across-level competition, assuming the absence of within-level competition to mitigate intractability and the potential for multiple equilibria which is common in Markov perfect equilibria, and aims to provide a unique equilibrium solution for practical and counterfactual models through a full-solution solution method. While the utilization of Markov perfect equilibria involves additional technical procedures for testing and estimation, as formally discussed in Otsu and Pesendorfer (2023), recent survey papers on empirical dynamic game literature underscore the importance of achieving equilibrium uniqueness and tractability. These surveys also summarize various theoretical conditions (Aguirregabiria *et al.* 2021). Alternatively, Abbring and Campbell (2010) develop an entry model with identical firms, assuming entry and exit decisions follow a last-in-first-out (LIFO) structure. This model achieves a unique equilibrium by introducing assumptions about the demand process. It is worth noting that this uniqueness result typically applies to identical firms. Extending their approach to nonstationary and asymmetric settings would be a significant contribution to the literature.

Another avenue for further research is to compare the current model with a cartel formation and breakdown model that incorporates well-documented institutional details and data. While this paper primarily focuses on specific aspects of shipping conferences as a case study, investigating a general empirical model that encompasses both explicit and implicit cartel models as summarized in Marshall and Marx (2014) and Asker and Nocke (2021) would be a valuable contribution to the literature.

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Appendix (For Online Publication)

This Appendix is prepared for online publication and contains supplementary materials. Table 11 lists the contents.

Appendix	Contents	
A	Computational details	Algorithm, Confidence Intervals, Computational time, Discretization
B	Data details	Data construction, Merger issues
C	Model details	The link between my model and Porter (1983)
D	Additional estimation results	Data fitting

Table 11: Contents of the Appendix

A Computation details

A.1 Algorithm

I construct the algorithm by applying Igami (2017, 2018) to my model setting. I fix targeted parameter θ_π. For exposition, I focus on market $m = 1$. I vectorize all state variables into s_{mt} and it takes a value from 1 to S. As in the empirical exercise, I fix the number of potential entrants, N^{pe}_{mt}, to four. Note that, at the equilibrium, fixed points of CCPs generate corresponding value functions. The algorithm to compute value functions via backward induction proceeds as follows.

Algorithm 1: Value Functions and CCPs

1. For $t = T-1, \cdots, 1$, obtain the value function at $t+1$ denoted by $V_{imt+1}(s_{mt+1})$. Given θ_π, obtain exit cost ψ, operation cost O, and investment cost I.

   (a) For $s_{mt} = 1, \cdots, S$, obtain the number of firms, N_{mt}, from s_{mt}.

   (b) Initialize and obtain old $E[V_{imt+1}(s_{mt+1})|s_{mt}]$ and old $Pr(a_{imt}|s_{mt})$ for all $a_{imt} \in \mathcal{A}^{inc}$ and $i \in \mathcal{N}_{mt}$.

   (c) Initialize and obtain old $E[V_{imt+1}(s_{mt+1})|s_{mt}]$ and old $Pr(a_{imt}|s_{mt})$ for all $a_{imt} \in \mathcal{A}^{pe}$ and $i \in \mathcal{N}^{pe}_{mt}$.

   (d) Then, find fixed points of CCPs as follows.

      (i) For level $l = 4$ and for all $a_{imt} \in \mathcal{A}^{inc}$ and $i \in \mathcal{N}^{l}_{mt}$,

         A. Given old $E[V_{imt+1}(s_{mt+1})|s_{mt}]$, old $Pr(a_{imt}|s_{mt})$, N_{mt}, and N^{pe}_{mt}, compute the joint likelihood

         $$\left(P^{pe}(N^{pe}_{mt}, X^{pe}_{mt} \mid s_{mt}; \theta_\pi) \prod_{l=1}^{4} P^{l}(N^{l}_{mt}, X^{l}_{mt}, B^{l}_{mt} \mid s_{mt}; \theta_\pi) \right)$$

         for all $N^{pe}_{mt}, X^{pe}_{mt}, N^{l}_{mt}, X^{l}_{mt}$, and B^{l}_{mt} for $l = 1, 2, 3, 4$.

         B. Given the joint likelihood, N_{mt}, and N^{pe}_{mt}, compute the transition probability $P(s_{mt+1}|s_{mt})$ for all $s = 1, \cdots, S$.

C. Given the joint likelihood, the transition probability, and $V_{imt+1}(s_{mt+1})$, compute the new expectation

$$E[V_{imt+1}(s_{mt+1})|s_{mt}] = \sum_{s_{mt+1}=1}^{S} P(s_{mt+1}|s_{mt})V_{imt+1}(s_{mt+1}),$$

then update old $E[V_{imt+1}(s_{mt+1})|s_{mt}]$ of corresponding actions to new $E[V_{imt+1}(s_{mt+1})|s_{mt}]$.

D. Given the new $E[V_{imt+1}(s_{mt+1})|s_{mt}]$, compute new $Pr(a_{imt}|s_{mt})$. If the new probability is overflown, go to 1 with new θ_π.

E. Obtain (CCP gap of incumbents) = new$Pr(a_{imt}|s_{mt})$ − old$Pr(a_{imt}|s_{mt})$.

F. Update old$Pr(a_{imt}|s_{mt})$ to (new$Pr(a_{imt}|s_{mt})$ + old$Pr(a_{imt}|s_{mt})$)/2.

G. Update $l = l - 1$ and go to (A) until $l = 1$.

(ii) For potential entrants,

A. Given the old $E[V_{imt+1}(s_{mt+1})|s_{mt}]$, old $Pr(a_{imt}|s_{mt})$, N_{mt}, and N_{mt}^{pe}, compute the joint likelihood.

B. Given the joint likelihood, N_{mt}, and N_{mt}^{pe}, compute the transition probability.

C. Given the joint likelihood, the transition probability, and $V_{imt+1}(s_{mt+1})$, compute new $E[V_{imt+1}(s_{mt+1})|s_{mt}]$ from the old $Pr(a_{imt}|s_{mt})$. Update the old $E[V_{imt+1}(s_{mt+1})|s_{mt}]$ of corresponding actions to new $E[V_{imt+1}(s_{mt+1})|s_{mt}]$.

D. Given the new $E[V_{imt+1}(s_{mt+1})|s_{mt}]$, compute new $Pr(a_{imt}|s_{mt})$. If the new probability is overflown, go to 1 with new θ_π.

E. Obtain (CCP gap of potential entrants) = new$Pr(a_{imt}|s_{mt})$ − old$Pr(a_{imt}|s_{mt})$.

F. Update old$Pr(a_{imt}|s_{mt})$ to (new$Pr(a_{imt}|s_{mt})$ + old$Pr(a_{imt}|s_{mt})$)/2.

(iii) Check (CCP gap of incumbents) + (CCP gap of potential entrants) < 0.01. If it is true, new$Pr(a_{imt}|s_{mt})$ is a fixed point. Otherwise, go to (i) again.

(iv) Given new$Pr(a_{imt}|s_{mt})$ and new$E[V_{imt+1}(s_{mt+1})|s_{mt}]$, compute value function $V_{imt}(s_{mt})$.

By nesting the above Algorithm 1 for value functions and CCPs as an inner loop, we evaluate the joint log-likelihood $ll_m(\theta_\pi)$ of observing choices in data as an outer loop. I use the Nelder-Mead algorithm for the outer loop. For the inner loop 1-(d), I implement policy function iteration based on the updating rule similar to the algorithm of Kasahara and Shimotsu (2012) which shows a good contraction property.

A.2 Calculation of confidence intervals

I calculate 90% confidence intervals using likelihood ratio tests, which involve comparing $ll(\hat{\theta}_\pi) - ll(\tilde{\theta}_\pi)$ with the corresponding critical values from a χ^2 distribution. Here, $ll(\theta_\pi)$ is the joint logarithmic likelihood evaluated at a vector of parameter values $\hat{\theta}_\pi$, and $\tilde{\theta}_\pi$ represents the maximum likelihood estimate (MLE) and its perturbed counterpart, respectively. I do not use standard errors based on Wald-type tests because the likelihood function exhibits a step function-like shape due to the game-theoretic nature of the model, as discussed in Igami (2017, 2018) and Igami and Uetake (2020). Specifically, for each parameter, I calculate the difference between the original likelihood and the likelihood evaluated at perturbed parameters, which consist of the four original parameters and one perturbed parameter. The perturbed parameter is chosen from eleven-grid intervals centered on the corresponding point-estimated value. Then, find lower and upper bounds of the perturbed parameter satisfying that $ll(\hat{\theta}_\pi) - ll(\tilde{\theta}_\pi)$ is less than the χ^2 critical value for the corresponding degrees of freedom.

A.3 Computational time

The main computational burden comes from Algorithm 1, in particular, finding fixed points for all state variables. Using appropriate starting values, it takes at least a week for the transatlantic market and two months for the transpacific market to estimate θ_π. Depending on the grids of perturbed parameters, it takes several days for all markets to calculate confidence intervals. It takes some minutes to simulate 1,000 equilibrium paths based on estimated CCPs.

A.4 Discretization details

To compute equilibrium outcome from discretized tonnage size in the static part, I need to recover "actual" tonnage size from the corresponding discretized tonnage size. This procedure depends on the representative value between grid points. Because I use common grid levels for all three markets, which are heterogeneous, for consistent comparison in the dynamic part, I should not use common representative values for all markets. To alleviate this limit in the view of data-fitting, I specify the representative values for each market based on fitting the equilibrium prices, quantities, and total tonnage size to the data. I specify the representative values for the Asia-Europe market as

$$\tilde{s}_{imt} = \begin{cases} 10.5 & \text{if } s_{imt} = 4 \\ 10.0 & \text{if } s_{imt} = 3 \\ 9.0 & \text{if } s_{imt} = 2 \\ 8.0 & \text{if } s_{imt} = 1. \end{cases}$$

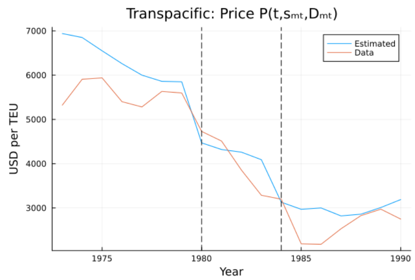
For the transpacific market,

$$\tilde{s}_{imt} = \begin{cases} 10.5 & \text{if } s_{imt} = 4 \\ 9.5 & \text{if } s_{imt} = 3 \\ 8.5 & \text{if } s_{imt} = 2 \\ 8.0 & \text{if } s_{imt} = 1. \end{cases}$$

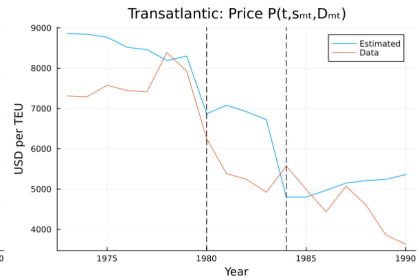
For the transatlantic market,

$$\tilde{s}_{imt} = \begin{cases} 12.1 & \text{if } s_{imt} = 4 \\ 10.1 & \text{if } s_{imt} = 3 \\ 9.2 & \text{if } s_{imt} = 2 \\ 7.2 & \text{if } s_{imt} = 1. \end{cases}$$

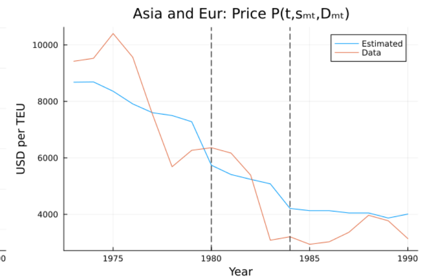
Figure 8 shows that equilibrium elements conditional on the actual states in the data capture the data patterns well, although some lags and deviations from the data exist due to the discretization. The equilibrium profits illustrate the market heterogeneity of the markup across all levels of firms.



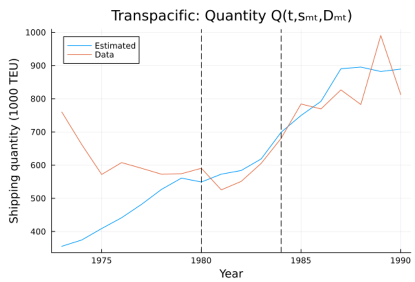
(a) Transpacific P_{mt}



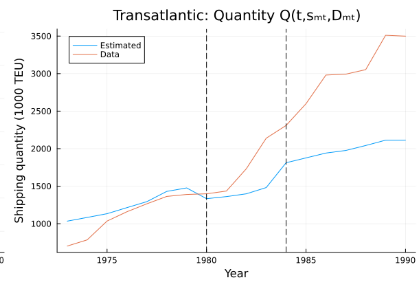
(b) Transatlantic P_{mt}



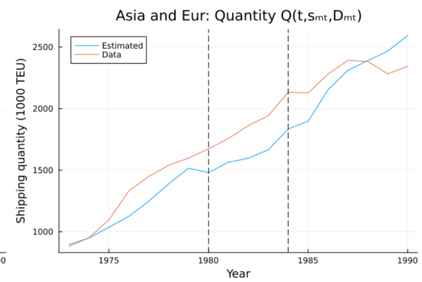
(c) Asia and Eur P_{mt}



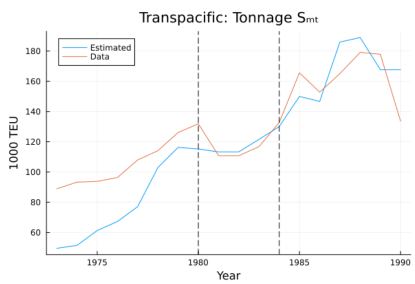
(d) Transpacific Q_{mt}



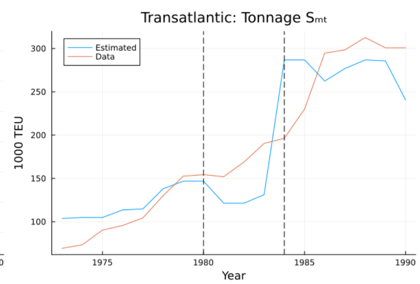
(e) Transatlantic Q_{mt}



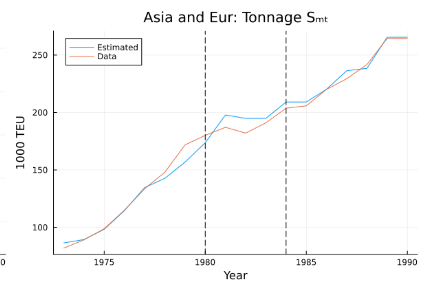
(f) Asia and Eur Q_{mt}



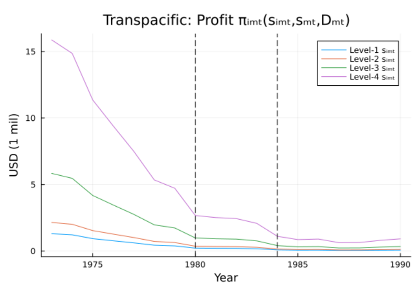
(g) Transpacific S_{mt}



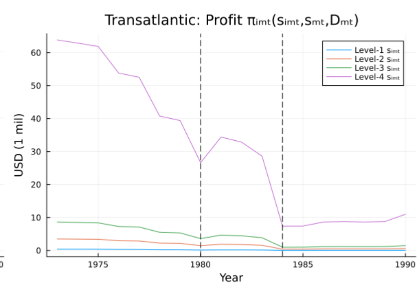
(h) Transatlantic S_{mt}



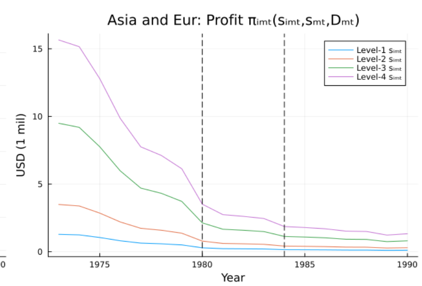
(i) Asia and Eur S_{mt}



(j) Transpacific π_{mt}



(k) Transatlantic π_{mt}



(l) Asia and Eur π_{mt}

Figure 8: Estimated market-year-level prices, quantities, total tonnage, and firm's profit of each level.

Note: Each element is derived from the discretized actual state in the data.

B Data details

The route-year-level prices and quantities are constructed based on Otani and Matsuda (2023a). The industry-year-level merger patterns between 1966 and 2022 are discussed in Otani and Matsuda (2023b). Mergers in the ocean shipping industry before the introduction of global container transportation are studied by Otani (2021) regarding Japanese shipping consolidation in 1964. In the period between 1973 and 1990, two mergers occurred in 1986, three mergers occurred in 1988, and two mergers occurred in 1990. The final two mergers do not affect my analysis because the data records ship-level information of merged firms in 1990. Although the other five mergers may affect my analysis, I treat merged firms as exiting firms from shipping conferences and merging firms as investing firms if their state variables in the next period show level-up due to data limitation because there are at most two mergers at market-year-level and multiple simultaneous mergers are difficult to model unlike month-industry-level sequential merger decisions of Igami and Uetake (2020).

C Model details

C.1 The link between my model and Porter (1983)

There is a link between my model and Porter (1983) who studies a "Joint Executive Committee railroad cartel" in the U.S. railroad industry. Concretely, my model does not model strategic interaction in the static market but assumes that the static market is either collusive or perfectly competitive, and markup is determined by cartel effects which are constant and exogenously determined by cartels. In contrast, Porter (1983) models strategic interaction as quantity competition with conduct parameters that determine perfect collusion to perfect competition, and the markup is determined endogenously by quantity competition under specific conduct parameters. First, my model and Porter (1983) are equivalent in competitive markets except for the tonnage size term which is given in the static model. Second, my model and Porter (1983) are different in collusive markets because my model is agnostic about the cartel behavior and treats collusive behavior as a deviation from perfectly competitive behavior, whereas Porter (1983) assumes that cartels choose the total quantity to maximize their joint profit. This difference comes from the difference in how a researcher interprets prices in the collusive regime in data.

Porter (1983) assumes a constant elasticity demand model, $\log(Q_{rt}) = \alpha_0 + \alpha_1 \log(P_{rt}) + \zeta_{rt}$ as in (6) where I use the same demand parameters because it has the same role between my model and Porter (1983). Porter (1983) also specifies firm i's marginal cost as $mc_{irt}(q_{irt}) = \tilde{\gamma}_1(a_{ir}q_{irt}^{\tilde{\gamma}_1-1})$ where a_{ir} is a firm-specific shift parameter and $\tilde{\gamma}_1(>1)$ is the parameter of the marginal cost different from γ_1 in my model. Note that since my model assumes $mc_{irt}(q_{irt}, s_{irt}) = \gamma_0 + \gamma_1 \frac{q_{irt}}{s_{irt}}$ in (2), the inverse tonnage size term, $1/s_{irt}$, captures the similar but time-varying firm-specific shift parameter.

The firms' actions under different behavioral assumptions can then be summarized by

$$P_{rt}(1 + \frac{\theta_{it}}{\alpha_1}) = mc_{irt}(q_{irt}) = a_{ir}\tilde{\gamma}_1 q_{irt}^{\tilde{\gamma}_1-1}$$

where θ_{it} is the conduct parameter Bresnahan (1982). If firms choose price noncooperatively or at a perfectly competitive level, they price at marginal cost, and so θ_{it} equals zero for all i and t. If instead they maximize joint profits, θ_{it} equals one for all i and t. If firms produce at Cournot output levels, θ_{it} equals q_{irt}/Q_{rt}, i.e., the firm i's market share in period t.

The individual supply equations are weighted by market shares and added up. Then, we get the industry supply relationship

$$P_{rt}(1 + \frac{\theta_t}{\alpha_1}) = \sum_{i \in \mathcal{N}_{rt}} \frac{q_{irt}}{Q_{rt}} mc_{irt}(q_{irt}),$$

where $\theta_t = \sum_{i\in\mathcal{N}_{rt}} \frac{q_{irt}}{Q_{rt}}\theta_{it}$. Porter (1983) shows that firm i's market share, $\frac{q_{irt}}{Q_{rt}}$, is constant, $\frac{a_{ir}^{1/(1-\tilde{\gamma}_1)}}{\sum_{i\in\mathcal{N}_{rt}} a_{ir}^{1/(1-\tilde{\gamma}_1)}}$, for all t in each of the three cases above. Note that higher the value of the firm-specific variable cost shift parameter, a_{ir}, lower the market share of firm i. The supply relationship can now be written as

$$P_{rt}(1+\frac{\theta_t}{\alpha_1}) = \tilde{\gamma}_1(\sum_{i\in\mathcal{N}_{rt}} a_i^{1/(1-\tilde{\gamma}_1)})^{1-\tilde{\gamma}_1} Q_{rt}^{\tilde{\gamma}_1-1}.$$

Suppose I_{rt} is an indicator variable that equals one when the industry is in a cooperative regime and equals zero when the industry witnesses a reversionary episode. Then, the supply relationship of the industry is given by

$$\begin{aligned}\log P_{rt} &= \log\left(\tilde{\gamma}_1(\sum_{i\in\mathcal{N}_{rt}} a_i^{1/(1-\tilde{\gamma}_1)})^{1-\tilde{\gamma}_1}\right) + (\tilde{\gamma}_1 - 1)\log Q_{rt} + \log((1+\frac{\theta_{rt}}{\alpha_1})^{-1}) \\ &= \tilde{\beta}_0 + \tilde{\beta}_1 \log Q_{rt} + \log(\frac{\alpha_1}{1+\alpha_1}) I_{rt},\end{aligned}$$

where $\tilde{\beta}_0 = \log\left(\tilde{\gamma}_1(\sum_{i\in\mathcal{N}_{rt}} a_i^{1/(1-\tilde{\gamma}_1)})^{1-\tilde{\gamma}_1}\right)$ and $\tilde{\beta}_1 = (\tilde{\gamma}_1 - 1)$. Porter (1983) estimates $\tilde{\beta}_0, \tilde{\beta}_1$ and $\log(\frac{\alpha_1}{1+\alpha_1})$.

If the marginal cost is given by (2) in my model, the supply relationship can now be written as

$$\begin{aligned}P_{rt}(1+\frac{\theta_t}{\alpha_1}) &= \sum_{i\in\mathcal{N}_{rt}} \frac{q_{irt}}{Q_{rt}}(\gamma_0 + \gamma_1 \frac{q_{irt}}{s_{irt}}) \\ &= \sum_{i\in\mathcal{N}_{rt}} \frac{s_{irt}}{S_{rt}}(\gamma_0 + \gamma_1 \frac{q_{irt}}{s_{irt}}) \\ &= \frac{\gamma_0}{S_{rt}} \sum_{i\in\mathcal{N}_{rt}} s_{irt} + \frac{\gamma_1}{S_{rt}} \sum_{i\in\mathcal{N}_{rt}} q_{irt} \\ &= \gamma_0 + \gamma_1 \frac{Q_{rt}}{S_{rt}},\end{aligned}$$

where the second equation comes from the property that tonnage capacity shares determine service quantity shares, the third equation comes from the constant cost parameters, and the fourth equation comes from the aggregations of individual capacities and quantities. First, this relationship implies that my model and Porter (1983) are equivalent in competitive markets except for the tonnage size term, S_{rt}, which is given in the static model. Second, to give a structural sense, it is necessary to additionally assume that cartels choose their total quantity to maximize their partially joint profit, then the collusive additional markup is $\frac{\theta_t P_{rt}}{-\alpha_1}$ that depends on P_{rt}. In other words, my model interprets observed collusive prices as competitive prices plus cartel effects $\tilde{\gamma}$, whereas Porter (1983) interprets observed collusive prices as $P_{rt}(1+\frac{\theta_t}{\alpha_1})$.

In the main text, under the above trade-off, I choose to use the model in which I am agnostic on cartel behavior. There are some reasons. First, container shipping firms provide shipping services on their fixed schedules between ports, so it is difficult to adjust the total service quantity to some target level. Second, shipping cartels can control prices to compete with non-conference firms out of the model so a joint profit maximization model based on quantity competition might be inappropriate. Third, the assumptions of Porter (1983) that capacity information does not matter in marginal costs and the output shares of cartel members are relatively stable across the regimes are inadequate in my data on nonstationary industry history with entry, exit, and investment of many firms, shown in Section 2. In my model, tonnage capacity s_{irt} determines the marginal cost efficiency of firm i and gives a link between static and dynamic parts of investment decisions, that are ignored by Porter (1983) assuming stationary markets. Fourth, as a practical reason, the sample size of my route-year-level data is not large enough for estimating potentially time-varying conduct parameters, discussed in Matsumura and Otani (2023a,b,c). My modeling choice is similar to Igami (2015) which recovers marginal costs from competitive regimes and calculates collusive markups as collusive prices minus the average of recovered marginal costs without any model of the coffee cartels.

C.2 Qualitative analysis of an individual capacity on revenue, total cost, and profit

I analyze how dynamic decisions changing tonnage capacities affect static profits. Note that in the static model, capacities for all firms, $s_{rt} = (s_{irt}, s_{-irt})$, are given. Also, the dynamic decisions on capacities are discretized, so the following analysis provides an approximated intuition treating capacities as continuous variables.

In Equation (5), firm i in route r in year t has the profit defined as follows:

$$\pi_{irt}(s_{irt}, s_{rt}, D_{rt}) = \underbrace{P^*_{rt}(s_{rt}, D_{rt})q_{irt}}_{=\text{Revenue}} - \underbrace{\int_0^{q_{irt}} mc_{irt}(q, s_{irt}))dq}_{=\text{Total cost}},$$

$$\text{s.t.} \quad q_{irt} = \begin{cases} Q^*_{rt}(s_{rt}, D_{rt})\omega_{irt} & \text{if } t \leq 1983 \\ \frac{P^*_{rt}(s_{rt}, D_{rt}) - \gamma_0}{\gamma_1} s_{irt} & \text{otherwise}, \end{cases} \qquad \omega_{irt} \in [0,1], \forall i, \sum_{i=1}^{N_{rt}} \omega_{irt} = 1.$$

First, I analyze the first term on revenue. Fixing rivals' capacity, s_{-irt}, and taking the first-order condition with respect to s_{irt},

$$\begin{aligned}\frac{\partial(\text{Revenue})}{\partial s_{irt}} &= \frac{\partial P^*_{rt}(s_{rt}, D_{rt})}{\partial s_{irt}} q_{irt} + P^*_{rt}(s_{rt}, D_{rt}) \frac{\partial q_{irt}}{\partial s_{irt}} \\ &= \begin{cases} \underbrace{\frac{\partial P^*_{rt}(s_{rt}, D_{rt})}{\partial s_{irt}}}_{<0} q_{irt} + P^*_{rt}(s_{rt}, D_{rt})(\underbrace{\frac{\partial Q^*_{rt}(s_{rt}, D_{rt})}{\partial s_{irt}}}_{>0} \omega_{irt} + Q^*_{rt}(s_{rt}, D_{rt}) \frac{\partial \omega_{irt}}{\partial s_{irt}}) & \text{if } t \leq 1983 \\ \underbrace{\frac{\partial P^*_{rt}(s_{rt}, D_{rt})}{\partial s_{irt}}}_{<0} q_{irt} + P^*_{rt}(s_{rt}, D_{rt})(\underbrace{\frac{\partial P^*_{rt}(s_{rt}, D_{rt})}{\partial s_{irt}}}_{<0} \frac{s_{irt}}{\gamma_1} + \frac{P^*_{rt}(s_{rt}, D_{rt}) - \gamma_0}{\gamma_1}) & \text{otherwise}, \end{cases}\end{aligned}$$

where the signs come not from solving fixed points of equilibrium prices and quantities in Section 3.2 because these cannot be derived as analytical forms. Due to dependency on the levels of q_{irt}, $P^*_{rt}(s_{rt}, D_{rt})$, s_{irt}, estimated parameters γ_0 and γ_1, and specification of ω_{irt}, I emphasize that the signs of remaining terms are not ex-ante determined. In my empirical application, the terms $\frac{\partial P^*_{rt}(s_{rt}, D_{rt})}{\partial s_{irt}}$ and $\frac{\partial P^*_{rt}(s_{rt}, D_{rt})}{\partial s_{irt}}$ are small because the marginal impacts of individual firms' capacities out of more than ten firms on the equilibrium prices and quantities are limited. Also, under the standard allocation rule such that firms with larger capacities provide more service quantities, it holds that $\frac{\partial \omega_{irt}}{\partial s_{irt}} > 0$. Additionally, my static estimation results confirm that $\gamma_1 > 0$ and $P^*_{rt}(s_{rt}, D_{rt}) - \gamma_0 > 0$ for all routes, which means that equilibrium prices are larger than the increasing marginal costs at zero quantity. Given these results of my specific application, $\frac{\partial(\text{Revenue})}{\partial s_{irt}} > 0$.

Next, I analyze the second term on the total cost. Fixing rivals' capacity, s_{-irt}, and taking the first-order condition with respect to s_{irt},

$$\frac{\partial(\text{Total cost})}{\partial s_{irt}} = \frac{\partial}{\partial s_{irt}}(\gamma_0 q_{irt} + \gamma_1 \frac{{q_{irt}}^2}{2s_{irt}} + C)$$
$$= -\gamma_1 \frac{{q_{irt}}^2}{2s_{irt}^2} < 0.$$

Therefore, taking the first-order condition of $\pi_{irt}(s_{irt}, s_{rt}, D_{rt})$ with respect to s_{irt},

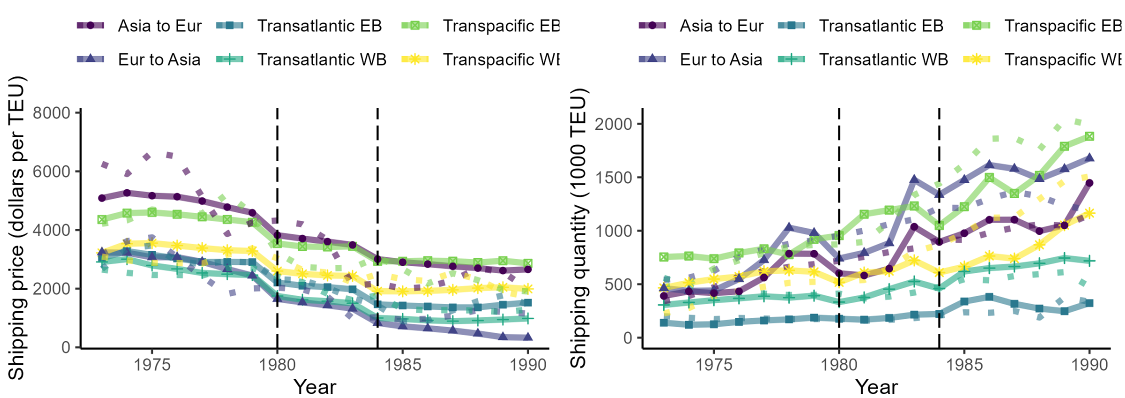
$$\frac{\partial \pi_{irt}(s_{irt}, s_{rt}, D_{rt})}{\partial s_{irt}} = \frac{\partial(\text{Revenue})}{\partial s_{irt}} - \underbrace{\frac{\partial(\text{Total cost})}{\partial s_{irt}}}_{<0},$$

and given my specific empirical application, $\frac{\partial(\text{Revenue})}{\partial s_{irt}} > 0$ so that $\frac{\partial \pi_{irt}(s_{irt}, s_{rt}, D_{rt})}{\partial s_{irt}} > 0$. Figures 8 (j), (k), and (l) show equilibrium profits conditional on actual states for each capacity level. This shows the above qualitative static-dynamic link that increasing capacities in the dynamic part increases static profits.

D Additional estimation results

D.1 Data fitting of the main models

Figures 9 (a) and (b) illustrate that the estimated route-year-level prices and quantities given in the demand part fit the data reasonably well, replicating the regime changes, albeit in a slightly smoother manner. Table 12 shows that estimated market-year-level prices from the supply side model fit the prices in data reasonably for each competition regime on average. However, the estimated standard deviation does not fit the standard deviation in the data because the sample size is small.



(a) P_{rt}: Estimated (solid) and data (dotted)

(b) Q_{rt}: Estimated (solid) and data (dotted)

Figure 9: Estimated route-year-level prices and quantities.

Table 12: Data fit for shipping prices for each regime.

Regime	Market	(1) Mean $\hat{P}_{mt}$	(2) Mean P_{mt}	(1)/(2)
1973-1979	Asia and Eur	3974.854	4172.739	0.953
	Transatlantic	2864.721	2791.502	1.026
	Transpacific	3920.995	3810.528	1.029
1980-1983	Asia and Eur	2569.928	2625.379	0.979
	Transatlantic	1848.499	2047.711	0.903
	Transpacific	2979.180	2724.519	1.093
1984-1990	Asia and Eur	1671.175	1672.949	0.999
	Transatlantic	1186.535	1331.900	0.891
	Transpacific	2444.903	2297.765	1.064

Note: Market aggregates eastbound and westbound routes. Estimated prices $\hat{P}_{mt}$ are calculated from the results of Table 4 (b).