Industrial Policy Implementation: Empirical Evidence from China's Shipbuilding Industry[*]

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Abstract

Industrial policies are widely used across the world. In practice, designing and implementing these policies is a complicated task. In this paper, we assess the long-term performance of different industrial policy instruments, which include production subsidies, investment subsidies, entry subsidies, and consolidation policies. To do so, we examine a recent industrial policy in China aiming to propel the country's shipbuilding industry to the largest globally. Using firm-level data from 1998 to 2014 and a dynamic model of firm entry, exit, investment, and production, we find that (i) the policy boosted China's domestic investment, entry, and international market share dramatically, but delivered low returns and led to fragmentation, idle capacity, as well as depressed world ship prices; (ii) the effectiveness of different policy instruments is mixed: production and investment subsidies can be justified by market share considerations, while entry subsidies are wasteful; (iii) counter-cyclical policies, firm-targeting, and shortening the intervention horizon can substantially reduce distortions. Our results highlight the critical role of firm heterogeneity, business cycles, and firms' cost structure in policy design. Finally, when exploring potential rationales, we find support for non-classical considerations, such as reducing freight rates to boost Chinese trade.

Keywords: Industrial policy, China, Investment, Dynamics, Shipbuilding

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1 Introduction

Industrial policy has been widely used in both developed and developing countries. Examples include the U.S. and Europe after World War II, Japan in the 1950s and 1960s (Johnson, 1982; Ito, 1992), South Korea and Taiwan in the 1960s and 1970s (Amsden, 1989; Lane, 2022), China, India, Brazil, and other developing countries more recently (Stiglitz and Lin, 2013; Peres, 2013). It is also back in the spotlight in developed countries, such as Europe and the US.[1] Designing and implementing industrial policies is a complicated task. Governments seeking to promote the growth of selected sectors have a wide range of policy tools at their disposal, including subsidies on output, provision of loans at below-market interest rates, preferential tax policies, tariff and non-tariff barriers, and so on. They must also choose the timing of policy interventions and whether to target selected firms within an industry. As Rodrik (2010) puts it, "The real question about industrial policy is not whether it should be practiced, but how." This paper tackles precisely this question.

We focus on China's shipbuilding industry which provides a clear illustration of the challenges associated with designing effective industrial policies. At the turn of the century, China's nascent shipbuilding industry accounted for less than 10% of the world production. During the 11th (2006-2010) and 12th (2011-2015) National Five-Year Plans, shipbuilding was dubbed a pillar industry in need of special oversight and consequently received numerous policy interventions. Within a few years, China overtook Japan and South Korea to become the world's leading ship producer in terms of output. However, this impressive output growth was achieved via a massive wave of new firms, which exacerbated industry fragmentation and low capacity utilization.[2] Plummeting ship prices during the aftermath of the financial crisis threatened the survival of many firms in the industry and prompted the government to place a moratorium on the entry of new firms. In the meantime, policy support was shifted towards selected firms on a "White List" in an effort to promote industry consolidation.[3]

The example of shipbuilding, which echoes patterns observed in other industries (steel, solar panels, auto, etc.), highlights the complexity of designing industrial policies and the difficulties associated with empirically evaluating past experiences. Policies that are implemented are often opaque; in addition, outcomes are affected by a large number of considerations, such as industry dynamics, business cycles, and firm heterogeneity. As a result, relative to the large theoretical literature on industrial policy and its popularity in practice, the empirical analysis is much more limited (see Lane, 2020 and Juhász et al., 2023 for excellent reviews).

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[1] See *The Economist* 2019: `https://www.economist.com/europe/2019/02/21/how-china-has-pushed-germany-to-rethink-industrial-policy`.

[2] This pattern is not unique to the shipbuilding industry. In many other industries that received government support in China in the 1990s and 2000s, such as steel, auto, and solar panels, sector growth was also characterized by the proliferation of small firms and an overall fragmented industry structure (Figure A1). This is in contrast to the experience of other countries. For example, South Korea's industrial policy of promoting heavy industries in the late 1970s ended up contributing to the dominance of large business conglomerates or the "chaebol" (Fukagawa, 1997).

[3] The "White List" consists of firms that "meet the industry standard" and thus receive priority in government support. See Section 2 for more details. Throughout this paper, we use "firms" and "shipyards" interchangeably.

This paper addresses two sets of questions. First, how did China's industrial policy affect the evolution of both the domestic and global industry? Second, what is the relative performance of different policy instruments, which include production subsidies (e.g., subsidized material inputs, export credits, buyer financing), investment subsidies (e.g., low-interest long-term loans, expedited capital depreciation), entry subsidies (e.g., below-market-rate land prices), and consolidation policies (White Lists)?

We first develop a structural model of the industry that incorporates dynamics and firm heterogeneity, both of which are essential for determining the long-term implications of industrial policy. In each period, firms engage in Cournot competition: they choose output subject to convex production costs and charge a markup. Then they decide whether or not to exit and how much to invest conditional on staying. Investment increases firm capital, which in turn reduces future production costs. Potential entrants make entry decisions based on their expected lifetime profitability and entry costs. China's industrial policy affects all of these decisions by lowering the relevant costs.

We then estimate the model using data on firm-level output, capital, and characteristics, as well as ship market prices from 1998 to 2014. The main primitives of interest are firm production costs, investment costs, entry costs, exit scrap values, the demand for ships, as well as the magnitude of subsidies. A critical challenge in our analysis is the lack of information on the nature of government subsidies. Partly because international trade agreements prohibit direct and in-kind subsidies, "systematic data are non-existent" (WTO, 2006) and thus the presence and magnitude of such subsidies are often unknown. This is a real hurdle to both domestic and international regulators who adjudicate subsidy disputes. To overcome this challenge, we follow the existing literature (see the literature review below) and recover the magnitude of subsidies by estimating the cost structure of Chinese firms before and after the policies were implemented, and in comparison to other countries when possible. Although this approach has its own caveats, it is the only feasible strategy next to observing the subsidies directly.

Our empirical strategy departs from the literature on firm dynamic decisions in two ways. First, we estimate the fixed costs of production from accounting data to accommodate sample periods when idling capacity and zero production plagued the industry. Second, we allow for continuous investment with unobserved cost shocks and adjustment costs in light of heterogeneous investment across firms with similar attributes. Once the key parameters are uncovered, we evaluate the long-term implications of China's industrial policy in counterfactual analysis, simulating the global shipbuilding industry over time and turning on and off different policy instruments as needed. Methodologically, our framework is quite general and can be adapted to the evaluation of other sector-specific industrial policies.

Our analysis delivers four sets of main findings. First, like many other policies unleashed by China's central government in the past decades, the scale of the policy is massive compared to the size of the shipbuilding industry. The discounted sum of entry subsidies (measured in constant RMB in the year 2000) is estimated at RMB 431 bn, followed by production subsidies at RMB 156 bn and investment subsidies at RMB 37 bn. Our estimates suggest that the policy support from 2006 to 2013 boosted China's domestic investment and entry by 140% and 120%, respectively, and increased its world market share by over 40%. Importantly, 70% of this expansion occurred via business stealing from rival countries (Japan and South Korea). These estimates corroborate raw data patterns. For example, aggregate investment by Chinese firms remained elevated post the financial crisis despite plummeting ship prices during the global recession.

On the other hand, the policy generated modest gains in domestic producers' profit and worldwide consumer surplus. In the long run, the gross return rate of the adopted policy mix, as measured by the lifetime profit gains of domestic firms divided by total subsidies, is only 18%. The policy attracted a large number of inefficient producers and exacerbated the extent of excess capacity. Fixed costs of production further contributed to the low returns due to the volatile nature of the industry and firm idleness.

Second, the effectiveness of different policy instruments differs greatly. Production and investment subsidies can be justified if the goal is revenue maximization (the rate of return as measured by the ratio of increased industry revenue to subsidies is 153%), but entry subsidies are wasteful even by the revenue metric and lead to increased industry fragmentation and idleness. This is because entry subsidies attract small and inefficient firms; in contrast, production and investment subsidies favor large and efficient firms that benefit from economies of scale. Finally, distortions are convex so that the rate of return deteriorates when policies are used in conjunction, as is done in practice.

Third, our analysis suggests that the efficacy of industrial policy is significantly affected by the presence of boom and bust cycles, as well as by heterogeneity in firm efficiency, both of which are notable features of the shipbuilding industry. A counter-cyclical policy would outperform the pro-cyclical policy that was adopted by a large margin. Indeed, their effectiveness at raising long-term industry profit differs by nearly twofold, which is primarily driven by a composition effect (more low-cost firms operate in a bust compared to a boom) and the much more costly expansion during booms (due to convex production and investment costs). In addition, shortening the horizon over which the policy is implemented could further boost the returns, as temporary interventions mitigate the entry of inefficient firms and reinforce the increasing returns to scale in ship production, all else equal.

Fourth, we examine the consolidation policy adopted in the aftermath of the financial crisis, whereby the government implemented a moratorium on entry and issued a "White List" of firms that are prioritized for government support. This strategy was adopted in several industries to curb excess capacity and create national champions that can compete globally.[4] Consistent with the evidence discussed above, we find that targeting low-cost firms significantly reduces distortions. That said, the government's White List was suboptimal and favored state-owned enterprises (SOEs) at the expense of the most efficient firms.

Our results highlight potential mechanisms underlying industrial policies' diverging outcomes across countries. For instance, in East Asian countries where industrial policy was considered successful, the policy support was often conditioned on performance. In contrast, in Latin America where industrial policies were less effective, there were no mechanisms to weed out non-performing beneficiaries (Rodrik, 2009). Our analysis illustrates that similar mechanisms are at work in China's modern-day industrial policy in the shipbuilding industry. The policy's return was low in earlier years when output expansion was primarily fueled by the entry of inefficient firms, but increased considerably over time as the gov-

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[4] See `https://www.wsj.com/articles/SB10001424127887324624404578257351843112188`.

ernment used ‘performance-based’ criteria (the White List) to channel subsidies. Such targeted policy design is substantially more successful than open-ended policies that benefit all firms.

Finally, we examine possible rationales for the policy we study. Strategic trade considerations are largely irrelevant because the shipbuilding industry is fragmented globally and market power is limited. There is no evidence of industry-wide learning-by-doing (Marshallian externalities), another common rationale for industrial policy. In terms of spillovers to the rest of the economy, we find limited evidence that the shipbuilding industry generates significant spillovers to other domestic sectors (e.g., steel production or the labor market).

On the other hand, the substantial increase in the global fleet ensuing from China’s increase in ship production did lower freight costs and increased China’s imports and exports. Our (back of the envelope) calculations indicate that government subsidies, which averaged \$11.3bn annually between 2006 and 2013, lowered freight rates by 6% and boosted China’s trade volume by 5%, or \$144bn annually.[5] That said, evaluating the welfare gains of the associated increase in trade volume requires a general equilibrium trade model and falls beyond the scope of this paper. There is also some evidence that military ship production might have benefited from China’s industrial policy: military ship production is concentrated at state-owned yards with commercial ship production and increased severalfold during the same period. However, this is suggestive due to limited data coverage. Regardless of the motivation, our analysis estimates the policy’s costs and assesses the relative efficacy of different policy instruments.

Related Literature There is a large theoretical literature on industrial policy (Hirschman, 1958; Baldwin, 1969; Krueger, 1990; Krugman, 1991; Harrison and Rodriguez-Clare, 2010; Stiglitz et al., 2013; Itskhoki and Moll, 2019). The earlier empirical literature on industrial policy mostly focuses on describing what happens to the benefiting industries (or countries) with regards to output, revenue, and growth rates (Baldwin and Krugman, 1988; Head, 1994; Luzio and Greenstein, 1995; Irwin, 2000; Hansen et al., 2003), while recent studies recognize the importance of measuring the impact on productivity and cross-sector spillovers (Aghion et al., 2015; Lane, 2022; Liu, 2019; Manelici and Pantea, 2021; Choi and Levchenko, 2021; Juhász et al., 2022). Related literature analyzes trade policies, in particular export subsidies (Das et al., 2007), R&D subsidies (Hall and Van Reenen, 2000; Bloom et al., 2002; Wilson, 2009), place-based policies targeting disadvantaged geographical areas (Kline and Moretti, 2014; Neumark and Simpson, 2015; Criscuolo et al., 2019), and environmental subsidies (Yi et al. 2015; Aldy et al. 2018).

Much of the existing literature focuses on whether an industrial policy should be implemented and which sectors should be targeted. Our analysis is complementary to the literature. We take a targeted sector as given and examine the design of industrial policy, a question that has received much less attention in prior work. To the best of our knowledge, our paper provides the first structural analysis of the design and performance of a large-scale industrial policy using firm-level data. The key features of our analysis are rich firm heterogeneity and market power, real business cycles and firm dynamics, and a variety of policy instruments. How industrial policy is implemented can radically affect the dynamic evolution of

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[5] The conversion rate for this period was 6.88 RMB for 1 U.S. dollar.

an industry. At the same time, different policy instruments entail very different returns.

Our paper also contributes to the growing literature studying how China's industrial development has been shaped by a variety of policy interventions, including consolidation policies (Rubens, 2021), R&D tax incentives (Chen et al., 2021), and value-added (VAT) tax reforms (Liu and Mao, 2019; Chen et al., 2019; Bai and Liu, 2019). In addition, our study builds on an emerging literature on the shipbuilding industry (Thompson, 2001, 2007; Hanlon, 2020). Kalouptsidi (2018) is closely related to our paper and detects evidence of production subsidies for a subset of bulk carriers (Handysize). In contrast, we examine the design, implementation, and efficacy of China's overall industrial policy and its impact on the global shipbuilding industry.

Methodologically, we build on the literature on dynamic estimation, including Bajari et al. (2007); Ackerberg et al. (2007); Pakes et al. (2007); Xu (2008); Aw et al. (2011); Ryan (2012); Collard-Wexler (2013); Sweeting (2013); Barwick and Pathak (2015); Fowlie et al. (2016), as well as the macro literature on firm investment (Abel and Eberly, 1994; Cooper and Haltiwanger, 2006). Complementing the macro literature that focuses on inaction (zero investment) and adjustment costs, our approach can rationalize different investment chosen by observably similar firms, while accommodating inaction and adjustment costs. Our analysis of firm investment builds on Ackerberg et al. (2007) and provides one of the first empirical applications of this model with continuous investment. This approach can be used in a variety of settings where heterogeneity in investment is an important consideration. In addition, our framework is quite general and can be easily adapted to the evaluation of other sector-specific industrial policies. Finally, our approach to estimating the subsidies follows a long tradition in the literature (Bruce, 1990; Young, 2000; Anderson and Van Wincoop, 2004; Poncet, 2005; Kalouptsidi, 2018; Barwick et al., 2020; Bai and Liu, 2019).

The rest of the paper is organized as follows. Section 2 provides an overview of China's shipbuilding industry and discusses the relevant industrial policy and our datasets. Section 3 presents the model. Sections 4 and 5 describe the estimation strategy and empirical results. Section 6 quantifies the policy impact on industry evolution and examines the performance of different policy instruments. Section 7 evaluates traditional rationales for industrial policy. Section 8 concludes.

2 Industry Background and Data

2.1 Industry Background

Shipbuilding is a classic target of industrial policy, often seen as a strategic industry for both commercial and military purposes. During the late 1800s and early 1900s, Europe was the dominant ship producer, especially the UK. After World War II, Japan subsidized shipbuilding along with several other industries to rebuild its industrial base and became the world's leader in ship production. South Korea went through the same phase in the 1970s and 1980s. In the 2000s, China supported the shipbuilding industry via a broad set of policy instruments.

The scope of national policies issued in China in the 2000s, especially after 2005, to support its shipbuilding industry is unprecedented. In 2002, former Premier Zhu inspected the China State Shipbuilding Corporation (CSSC), one of the two largest shipbuilding conglomerates in China, and pointed out that "China hopes to become the world's largest shipbuilding country (in terms of output) [...] by 2015." Soon after, the central government issued the 2003 *National Marine Economic Development Plan* and proposed constructing three shipbuilding bases centered at the Bohai Sea area (Liaoning, Shandong, and Hebei), the East Sea area (Shanghai, Jiangsu, and Zhejiang), and the South Sea area (Guangdong).

The most important initiative was the 11th National Five-Year Economic Plan (2006-2010) which dubbed shipbuilding as a strategic industry. Since then, the shipbuilding industry, together with the marine equipment industry and the ship-repair industry, has received numerous supportive policies. Zhejiang was the first province that identified shipbuilding as a provincial pillar industry. Jiangsu is the close second and set up dedicated banks to provide shipyards with favorable financing terms. In the 11th (2006-2010) and 12th (2011-2015) Five-Year plans, shipbuilding was identified as a pillar or strategic industry by twelve and sixteen provinces, respectively. Besides these Five-Year Plans, the central government issued a series of policy documents with specific production and capacity goals. For example, as part of the 2006 *Medium and Long Term Development Plan of Shipbuilding Industry*, the government set an annual production goal of 15 million deadweight tons (DWT) by 2010 and 22 million DWT by 2015. Both goals were met several years in advance. Table A1 and Appendix A.1 document major national policies issued during our sample period.

We group policies that supported the Chinese shipbuilding industry into three categories based on policy documents: production, investment, and entry subsidies. Production subsidies lower the cost of producing ships. For instance, the government-buttressed domestic steel industry provides cheap steel, which is an important input for shipbuilding. Besides subsidized input materials, export credits (Collins and Grubb, 2008) and buyer financing in the form of collateral loans provided by government-directed banks constitute other important components of production subsidies.[6] Buyer financing is important because shipyards have traditionally offered loans and financial services to facilitate purchasing payments and attract buyers. Investment subsidies take the form of low-interest long-term loans and preferential tax policies that allow for accelerated capital depreciation.[7] Finally, shortened processing time and simplified licensing procedure, as well as heavily subsidized land prices along the coastal regions greatly lower the entry costs for potential shipyards.

In response to the 2008 economic crisis that led to a sharp decline in global ship prices and in an effort to curb excess capacity and industry fragmentation, the government unveiled the 2009 *Plan on Adjusting and Revitalizing the Shipbuilding Industry* that resulted in an immediate moratorium on entry with increased investment subsidies to existing firms. This marked an important shift in China's policy in this sector, where government support moved toward facilitating consolidation and creating

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[6] Until 2016, the Chinese government subsidized exporters using reduced corporate income taxes and refund of the value-added-tax, etc. Shipyards benefit from export subsidies since their products are mostly traded internationally.

[7] China implemented a value-added tax reform in 2009 that might have stimulated investment (Chen et al., 2019). This policy has limited impacts on shipyards, which are already exempt from value-added tax via exports subsidies.

large, successful firms that can compete against international conglomerates. The most crucial policy for achieving consolidation was the *Shipbuilding Industry Standard and Conditions* (2013), which instructed the government to periodically announce a list of firms that "meet the industry standard" and thus receive priority in subsidies and bank financing.[8] The so-called "White List" included sixty firms in 2014 upon announcement.

In this paper, we focus on the production of three ship types: dry bulk carriers, tankers, and containerships, which account for more than 90% of world orders in tons in our sample period. Dry bulk carriers transport homogeneous and unpacked goods, such as iron ore, grain, coal, and steel for individual shippers on non-scheduled routes. Tankers carry chemicals, crude oil, and other oil products. Containerships carry containerized cargo from different shippers in regular port-to-port itineraries. As these types of ships carry entirely different commodities, they are not substitutable. We thus treat them as operating in separate markets.

Shipbuilding worldwide is concentrated in China, Japan, and South Korea, which account for over 90% of the world production. We limit our empirical analysis to these three countries.

2.2 Data

Our empirical analysis draws on a number of datasets. The first dataset comes from Clarksons and contains quarterly information on all shipyards worldwide that produce ships for ocean transport between the first quarter of 1998 and the first quarter of 2014. We observe each yard's orders, deliveries, and backlog (which are undelivered orders that are under construction) measured in Compensated Gross Tons (CGT), for all major ship types, including bulk carriers, tankers, and containerships. CGT, which is a widely used measure of size in the industry, takes into consideration production complexities of different ships and is comparable across types.

The second data source is the annual database compiled by China's National Bureau of Statistics (NBS) on manufacturing firms. For each shipyard and year, we observe its location (province and city), balance-sheet information (including total fixed assets), and ownership status (state-owned enterprises (SOEs), privately owned, or joint ventures). We link firms over time and construct their real capital stock and investment from total fixed assets following Brandt et al. (2012), which is standard practice in the literature.[9] We differentiate SOEs that are part of China State Shipbuilding Corporation (CSSC) and China Shipbuilding Industry Corporation (CSIC), the two largest shipbuilding conglomerates in China, from other SOEs.

In addition to these firm-level variables, we collect a number of aggregate variables, including quarterly global prices per CGT for each ship type. The steel ship plate price serves as a cost shifter, as steel is a major input in shipbuilding. We merge all datasets to obtain a quarterly panel of Chinese, South Korean, and Japanese shipyards ranging from 1998 to 2013. All monetary variables (such as investment and

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[8] In practice, favorable financing terms and capital market access are often limited to firms on the White List post 2014.

[9] One limitation is that data for 2010 are missing. This prevents us from constructing firm-level investment in either 2009 or 2010 since investment is imputed from year-to-year changes in capital stock.

capital) are in real terms and measured in 2000 RMB. Appendix A.2 provides more details on variable construction and descriptive patterns.

2.3 Descriptive Evidence and Summary Statistics

Similar to many other manufacturing industries in China, the shipbuilding industry experienced exponential growth since the mid 2000s. China became the largest shipbuilding country in terms of CGT in 2009, overtaking South Korea and Japan. Panel (a) of Figure 1 plots China's rapid ascent into global influence from 1998 to 2013. At the same time, a massive entry wave of new shipyards occurred along China's coastal areas. Panel (b) plots the total number of new shipyards by year. The number of entrants is modest for Japan (1.4 per year) and South Korea (1.2 per year). In contrast, the number of new shipyards in China registered a historic record and exceeded 30 per year during the boom years when the entry subsidies were in place. Entry dropped to 15 in 2009 and became minimal within a couple of years of the implementation of the 2009 entry moratorium, as part of the *Plan on Adjusting and Revitalizing the Shipbuilding Industry*.[10]

The rise in entry was accompanied by a large and unprecedented increase in capital expansion (Panel (c) of Figure 1). The year of 2006 alone witnessed a steep four-fold increase in investment. The capital expansion was universal across both entrants and incumbents and among firms with different ownership statuses. For example, entrants accounted for 43% of the aggregate investment from 2006 to 2011, with the remaining 57% implemented by incumbents. Private firms, joint ventures, and SOEs accounted for 25%, 36%, and 38% of total investment, respectively. In addition, the capital expansion was spread out across provinces, though Jiangsu accounted for a disproportionate share of 40% of the aggregate investment between 2006 and 2011 (Figure A2).

The rapid rise in China's entry, production, and investment aligned remarkably well with the policy timelines. In contrast, the economic fundamentals (or market forces) do not appear to fully rationalize these data patterns. As Panel (d) of Figure 1 shows, ship prices began rising around 2003, peaked in 2008, collapsed in the aftermath of the financial crisis, and remained stagnant from 2009 to 2013. China's production and investment, on the other hand, continued to expand well after the financial crisis, in contrast to other countries.

Table 1 contains summary statistics on key variables of interest. There are a large number of firms, with 266 Chinese shipyards, 108 Japanese shipyards, and 46 Korean shipyards. Industry concentration is low, with a world HHI that varies from 230 to 720 during the sample period.

An important feature of ship production is that shipyards take new orders infrequently, about 23% of the quarters for bulkers and less frequently for tankers and containerships. From 2009 onwards, during a prolonged period of low ship prices, the frequency with which yards took new orders was significantly lower. This lumpiness in ship orders that rendered Chinese shipyards increasingly vulnerable to long

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[10] No new applications were processed post 2009, but projects already approved were allowed to be completed. In addition, firms registered prior to 2009 but engaged in repairs and marine engineering could 'enter' and produce ships post 2009. Both account for the entry (though at a far reduced rate) past 2009.

periods of inaction during the recession, is a key feature of the industry that informs our modeling choices in Section 3.

Finally, about 52% of firms in our sample produce one ship type, a pattern that holds across countries. The fraction of shipyards that produce all three ship types is higher in South Korea (28%) and Japan (16%) and lower in China (14%). If a shipyard never takes orders for a certain ship type throughout our sample, it is assumed not to produce this ship type.

3 Model

In this section, we introduce a dynamic model of firm entry, exit, and capital investment. In each period, incumbent firms engage in Cournot competition by choosing statically how much to produce. Then they choose whether or not to exit, and conditional on staying, how much to invest. A pool of potential entrants make one-shot entry decisions based on their expected discounted stream of profits and entry costs. At the end of the period, entry, exit, and investment decisions are implemented and the state evolves to the next period.

Time is discrete and a period is a quarter. In period t, there are $j = 1, ..., J_t$ firms. Ship type (dry bulk carriers, tankers, and containerships) is denoted by m. Ships within a type are homogeneous.

Ship Demand The aggregate inverse demand for ship type m at time t is given by:

$$P_{mt} = P_m\left(Q_{mt}, d_{mt}\right) \tag{1}$$

for $m = 1, ..., M$, where P_{mt} is the price of ship type m in period t, Q_{mt} is the total CGT demanded, and d_{mt} are demand shifters, such as freight rates and aggregate indicators of economic activity.

Ship Production Firm j produces q_{jmt} tons at the following cost:

$$C\left(q_{jmt}, s_{jmt}, \omega_{jmt}\right) = c_0 + c_m\left(q_{jmt}, s_{jmt}, \omega_{jmt}\right)$$

where c_0 is a fixed cost that is incurred even when shipyards have zero production, such as wages and benefits for managers, capital maintenance, land and rental costs, etc. Fixed costs are often abstracted away in empirical studies. In our context, where aggregate demand for new ships plummeted post the financial crisis and many shipyards reported prolonged periods with zero production, fixed costs constitute a substantial fraction of overall costs and thus should not be omitted.

The second term, $c_m(q_{jmt}, s_{jmt}, \omega_{jmt})$, is the variable production cost. We use s_{jmt} to denote firm characteristics (e.g. capital, backlog, age, location, ownership status), aggregate cost shifters that affect all shipyards (e.g. steel prices), and policy dummies that capture the effect of industrial policy on production costs. In addition, production costs depend on shock ω_{jmt}: the larger ω_{jmt} is, the less productive the firm is.

Firms engage in Cournot competition. They choose how many tons of ship type m to produce in each period, q_{jmt}, taking as given the production decisions of rival firms. If the optimal production tonnage for type m, q^*_{jmt}, is positive, it satisfies the following first order condition:

$$P_{mt} + q^*_{jmt}\frac{\partial P\left(Q_{mt}, d_{mt}\right)}{\partial q_{jmt}} = MC_m\left(q^*_{jmt}, s_{jmt}, \omega_{jmt}\right) \tag{2}$$

where $MC_m\left(q_{jmt}, s_{jmt}, \omega_{jmt}\right)$ is the marginal cost of producing type m. Firms charge a markup equal to $q^*_{jmt}\frac{\partial P(Q_{mt}, d_{mt})}{\partial q_{jmt}}$ (in absolute value), thus distorting the market output levels.

Firm Profit Let $s_{jt} = \{s_{j1t}, ..., s_{jMt}\}$ denote firm j's state variable at time t, which is the union of its state variables across ship types, the states of its rivals, as well as aggregate states. Industrial policies affect the costs of production, investment, and entry and are part of the payoff relevant state variables, s_{jt}. Firm j's expected profit from all types, before the cost shocks are realized, is:

$$\pi(s_{jt}) = \mathbb{E}\sum_{m=1}^{M}\pi_m(s_{jt}, \omega_{jmt})$$

where $\pi_m(s_{jt}, \omega_{jmt})$ is firm j's profit from producing ship type m, and $\mathbb{E}$ integrates out uncertainties in firms' production cost shocks.[11]

Finally, in each period, the prevailing ship price, P_{mt}, equates aggregate demand and supply, where the aggregate supply is the sum of q^*_{jmt} defined in (2).

Investment and Exit Once firms make their optimal production choice, they observe a private scrap (sell-off) value, ϕ_{jt}, that is i.i.d. with distribution F_ϕ and decide whether to remain in operation or exit. If a firm chooses to exit, it receives the scrap value. If it remains active, it observes a firm-specific random investment cost shock, ν_{jt}, that is i.i.d. with distribution F_ν, and chooses investment i_{jt} at cost $C^i(i_{jt}, s_{jt}, \nu_{jt})$. The amount invested, i_{jt}, is added to the firm's capital stock next period, which in turn affects its future production costs.

Let $V(s_{jt}, \phi_{jt})$ denote the ex-post value function after firm j observes its scrap value and $V(s_{jt})$ denote the ex-ante value function before the realization of the scrap value: $V(s_{jt}) \equiv \mathbb{E}_\phi V\left(s_{jt}, \phi_{jt}\right)$. The ex-post value function for incumbent firm j is:

$$\begin{aligned} V(s_{jt}, \phi_{jt}) &= \pi(s_{jt}) + \max\left\{\phi_{jt}, \mathbb{E}_{\nu_{jt}}\left(\max_i\left(-C^i(i, s_{jt}, \nu_{jt}) + \beta\mathbb{E}\left[V(s_{jt+1})|s_{jt}, i\right]\right)\right)\right\} \\ &= \pi(s_{jt}) + \max\left\{\phi_{jt}, CV(s_{jt})\right\} \end{aligned} \tag{3}$$

$$CV(s_{jt}) \equiv \mathbb{E}_{\nu_{jt}}\left(-C^i(i^*, s_{jt}, \nu_{jt}) + \beta\mathbb{E}\left[V(s_{jt+1})|s_{jt}, i^*\right]\right) \tag{4}$$

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[11] We take firms' product types as given and do not explicitly model their choice of which ship types to produce.

where $CV(s_{jt})$ denotes the continuation value, which includes the expected cost of optimal investment and the discounted future stream of profits. In addition, $\mathbb{E}_{\nu_{jt}}$ is the expectation with respect to the random investment cost shock ν_{jt} and i^* denotes the optimal investment policy $i^* = i^*(s_{jt}, \nu_{jt})$.

The optimal exit policy is of the threshold form: firm j exits the market if the drawn scrap value ϕ_{jt} is higher than its continuation value $CV(s_{jt})$. Since the scrap value is random, the firm exits with probability $p^x(s_{jt})$:

$$p^x(s_{jt}) \equiv \Pr\left(\phi_{jt} > CV(s_{jt})\right) = 1 - F_\phi\left(CV(s_{jt})\right) \tag{5}$$

where F_ϕ is the distribution of ϕ_{jt}.

Conditional on staying, firm j observes its investment shock, ν_{jt}. Its optimal investment $i^* = i^*(s_{jt}, \nu_{jt})$, which is non-negative, satisfies the first-order condition:

$$\beta \frac{\partial \mathbb{E}\left[V(s_{jt+1})|s_{jt}, i^*\right]}{\partial i} \leq \frac{\partial C^i(i^*, s_{jt}, \nu_{jt})}{\partial i} \tag{6}$$

with equality if and only if the optimal investment is strictly positive, $i^*(s_{jt}, \nu_{jt}) > 0$. When the investment costs are prohibitively high or the expected benefit too low, firms opt for no investment. Capital depreciates at rate δ that is common to all firms.

We assume that the cost of investment, $C^i(i_{jt}, s_{jt}, \nu_{jt})$, has the following form:

$$C^i(i_{jt}, s_{jt}, \nu_{jt}) = c_1(s_{jt})i_{jt} + c_2 i_{jt}^2 + c_3 \nu_{jt} i_{jt} \tag{7}$$

This quadratic specification borrows from the macro literature on convex investment costs (e.g. Cooper and Haltiwanger 2006) with some important differences. For example, investment costs depend on the unobserved marginal cost shock ν_{jt}. Much of the existing literature has focused on the lumpy nature of investment (inaction) and adjustment costs, but has not modeled heterogeneous investment decisions among observationally similar firms.[12] In practice, firms with similar attributes often invest very different amounts. We accommodate this by introducing ν_{jt} that shifts the marginal cost of investment across firms. Note that ν_{jt} can also explain inaction: firms with unfavorably large ν_{jt} will choose not to invest. Once we allow for ν_{jt}, additional adjustment costs, such as $\frac{i_{jt}^2}{k_{jt}}$ and/or a (random) fixed cost, contribute little to the model fit.[13]

Entry In each period t, $\bar{N}$ potential entrants observe the payoff relevant state variables and their private i.i.d. entry cost κ_{jt} before making a one-time entry decision. The entry cost is drawn from a distribution $F_\kappa(\kappa|s_{jt})$ that is shifted by industrial policy (which is part of the state variable s_{jt}). If potential entrant j decides not to enter, it vanishes with a payoff of zero. Otherwise, it pays the entry cost and continues

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[12] Notable exceptions include Ryan (2012) that models firm investment decisions as following an S-s rule and Collard-Wexler (2013) that analyzes discrete investment.

[13] The estimated fixed cost of investment is economically small and thus excluded. Fixed costs are associated with an inaction region where firms do not invest. The larger the fixed cost, the larger the inaction region. Firms do make small investments in our data, which is inconsistent with a large fixed cost.

as an incumbent in the next period. The entrant is assumed to be endowed with a random initial capital stock that is realized the following period once the firm becomes an incumbent and begins operation.

Potential entrant j solves:

$$\max\left\{0, -\kappa_{jt} + \mathbb{E}\left[-C^i(k_{jt+1}, s_{jt}) + \beta\mathbb{E}\left[V(s_{jt+1})|s_{jt}\right]\right]\right\}$$

where κ_{jt} is the entry cost and k_{jt+1} is entrant j's initial capital stock in period $t+1$ after paying a cost of $C^i(k_{jt+1}, s_{jt})$. The expectation is taken over entrant j's information set at time t, which includes all aggregate state variables.

Similar to the exit decision, the optimal entry policy is of the threshold form: a potential entrant enters the market if the entry cost κ_{jt} drawn is lower than the value of entering, i.e.

$$\kappa_{jt} \leq VE(s_{jt}) \equiv \mathbb{E}\left[-C^i(k_{jt+1}, s_{jt}) + \beta\mathbb{E}\left[V(s_{jt+1})|s_{jt}\right]\right]$$

Since κ_{jt} is random, the potential entrant enters with probability p^e_{jt} that is defined by:

$$p^e(s_{jt}) \equiv \Pr\left(\kappa_{jt} \leq VE(s_{jt})\right) = F_\kappa\left(VE(s_{jt})|s_{jt}\right) \tag{8}$$

Equilibrium A Markov-Perfect Equilibrium of this model consists of policies, $\{q^*_{jmt}\}_{m=1}^M$, $i^*(s_{jt}, \nu_{jt})$, $p^x(s_{jt})$, $p^e(s_{jt})$, value function $V(s_{jt})$ and prices P_{mt}, such that the production quantity satisfies (2) and maximizes the period profit, the exit policy satisfies (5), the investment policy satisfies (6), the entry policy satisfies (8), and ship prices clear the market each period so that aggregate ship demand equals aggregate supply. Moreover, the incumbent's value function satisfies (3) and firms employ the above policies to form expectations.[14]

Discussion We close this section with a brief discussion on our assumptions. We assume that ships are homogeneous within a type conditioning on size. To substantiate this assumption, we explore a subsample of new ship purchase contracts with detailed price information and ship attributes. Ship type, ship size in CGT, and quarter dummies explain most of the price variation: the R^2 of a hedonic price regression with only these regressors is 0.93 for bulkers, 0.94 for tankers, and 0.75 for containerships. Shipyard characteristics (age, country, number of docks and berths, etc.) have limited explanatory power: including shipyard fixed effects in the hedonic regressions adds little to the fit except for containerships where the R^2 increases moderately. On the ship buyer side (shipowners), monopsony power is not a first-order issue as the concentration among shipowners is low.

We assume away dynamic considerations in production. In practice, as producing a ship takes time, production today affects the backlog tomorrow, which affects tomorrow's operation costs and therefore production decisions. However, as documented in Kalouptsidi (2018) that allows for such dynamics,

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[14] The equilibrium existence follows from Ericson and Pakes (1995) and Doraszelski and Satterthwaite (2010).

cost function estimates are similar under the static and dynamic model, especially when it comes to the estimated subsidies. This is partly because the drastic production expansion observed cannot be explained by inter-temporal considerations that arise with dynamic production. We allow backlogs to affect the marginal cost of production, which proxies for dynamic considerations in a reduced-form manner.

Cost shocks ω_{jmt} are i.i.d. There are several reasons for this choice. First, ω_{jmt} is estimated to be moderately persistent, with a serial autocorrelation of 0.28 for bulkers, 0.27 for tankers, and 0.39 for containerships. Second, while it is straightforward to estimate the persistence of these shocks using quantity choices (Section 4.1), incorporating a persistent time-varying unobserved state variable in a dynamic model raises considerable computational challenges. For the same reason, investment cost shocks ν_{jt} are assumed i.i.d.

That said, our model does incorporate persistent effects through the backlog and capital stock. When firms experience favorable ω_{jmt} shocks, they increase orders and production and therefore backlog. Since backlog captures firms' production efficiency and is a state variable, firms with higher backlog invest more, which increases future capital stock and further lowers long-run production costs. This mechanism is the primary reason that ex-ante identical firms have different growth trajectories over time, as highlighted by Ericson and Pakes (1995).

Last, we follow the literature (Ryan, 2012) and assume that government policies are perceived as permanent by all firms. We assume that the equilibrium before and after the policy is stationary, given our rich set of state variables. Relaxing this assumption and estimating firms' expectations and adaptation to a changing environment is a difficult but important topic for future research (Doraszelski et al., 2018; Jeon, 2018).

4 Estimation Strategy

The key primitives of interest are the world demand function for new ships, the shipyard production cost function, the investment cost function, the distribution of scrap values, and the distribution of entry costs. We estimate the heterogeneous production cost function for shipyards in all countries but only analyze dynamic decisions (entry, exit, and investment) for Chinese shipyards. This is because aggregate data suggest that entry, exit, and capacity expansion are limited in Japan and South Korea (OECD, 2015, 2016) and because we do not have firm-level data on dynamic decisions for shipyards outside China. We recover the magnitude of the (unobserved) subsidies by estimating the production, investment, and entry costs of Chinese firms before and after each period of government intervention and in comparison to other countries when possible.

This section is self-contained and the reader may omit it and proceed to the results section if desired. Section 4.1 discusses estimation of the static parameters (demand and production costs). Sections 4.2.1 and 4.2.2 present the first and second stage of estimating dynamic parameters: investment cost, scrap values, and entry costs. Appendices B.1 - B.3 provide more details on estimation. Appendix B.4 discusses in detail the identification and data variation that allows us to estimate the model.

4.1 Estimation of Static Parameters

Demand The demand curve (1) for ship type m is parameterized as follows:

$$Q_{mt} = \alpha_{0m} + \alpha_{pm} P_{mt} + d'_{mt} \alpha_{dm} + \varepsilon^{d}_{mt} \tag{9}$$

The demand shifters d_{mt} include freight rates, the total backlog of type m, and type-specific variables. Demand for new ships is higher when demand for shipping services is high, reflected in higher freight rates.[15] Conversely, a large backlog implies that more ships will be delivered in the near future, which reduces demand for new ships today. We also control for aggregate indicators of economic activity relevant to each ship type: the wheat price and Chinese iron ore imports for bulk carriers, Middle Eastern refinery production for oil tankers, and world car trade for containerships. Some specifications include time trends. Finally, we allow the price elasticity to change before and after 2006, the main policy year.

Prices are instrumented by steel prices and steel production.[16] Steel is a major input in shipbuilding and contributes to 25 - 30% of the variable production costs (Jiang and Strandenes, 2012). The identification assumption is that steel prices and steel production are uncorrelated with new ship demand shocks ε^{d}_{mt} after controlling for primary economic factors relevant to ship demand. This is a plausible assumption because only a modest portion of global steel production is used in shipbuilding and an increase in ship demand ($\varepsilon^{d}_{mt} > 0$) is unlikely to have an impact on steel prices.[17] As there is a single global market for each ship type, the demand curves are estimated from time series variation.

Production Costs The marginal cost function $MC_m\left(q_{jmt}, s_{jmt}, \omega_{jmt}\right)$ is defined as:

$$MC_m(q_{jmt}, s_{jmt}, \omega_{jmt}) = \beta_{0m} + s'_{jmt}\beta_{sm} + \beta_{qm} q_{jmt} + \omega_{jmt}$$

where q_{jmt} denotes tons of ship type m produced by firm j in period t. Because of time to build, there are differences between orders placed, deliveries, and production in a given period. We use orders as a measure of q_{jmt} because the number of tons ordered is the relevant quantity decision made by the firm and responds to observed ship prices. In addition, our data source reports orders and deliveries instead of production and it is not straightforward to infer production from orders.

Cost shifters s_{jmt} include firm j's capital stock and its backlog of all ship types. Capital accumulates through investment over time and reduces production costs via economies of scale. Backlogs affect costs

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[15] The freight rate measures are the Baltic Exchange Freight Index for bulk shipping, the Baltic Exchange Clean Tanker Index for tankers, and the Containership Timecharter Rate Index for containerships.

[16] While demand elasticities in principle affect production cost estimates, they have a modest effect in our setting largely because markups are modest. See Section 5.4 for details.

[17] Internationally traded steel accounts for less than 8% of the volume transported by bulk carriers (UNCTAD, 2018). Thus, changes in steel prices (which affect steel transported) are unlikely to affect demand for bulk carriers.

through either economies of scale (e.g. large input purchases or simultaneous production of multiple ships) or capacity constraints (Jofre-Bonet and Pesendorfer, 2003). In addition, s_{jmt} contains shipyard j's age and ownership status, nationality and region (for Chinese firms), a dummy for large firms, the steel price, as well as polynomial terms of these state variables.[18] Lastly, s_{jmt} includes dummies for the policy intervention between 2006 and 2008 and then from 2009 onwards. The production cost shock ω_{jmt} is assumed to be normally distributed with mean zero and variance $\sigma^2_{\omega m}$.

The first-order condition of firm j's profit maximization problem is (allowing for zero quantity):

$$\begin{gathered} MR_{jmt} \leq MC_m(q_{jmt}, s_{jmt}, \omega_{jmt}) \\ P_{mt} + q_{jmt}\frac{\partial P_{mt}}{\partial q_{jmt}} \leq \beta_{0m} + s'_{jmt}\beta_{sm} + \beta_{qm} q_{jmt} + \omega_{jmt} \end{gathered}$$

Let $\bar{\beta}_{qm} = \frac{1}{\beta_{qm} - \bar{\alpha}_{pm}}$. The optimal quantity produced is characterized by the following equations:

$$\begin{aligned} q^*_{jmt} &= \bar{\beta}_{qm}(P_{mt} - \beta_{0m} - s'_{jmt}\beta_{sm} - \omega_{jmt}) \\ q_{jmt} &= max\{0, q^*_{jmt}\} \end{aligned} \tag{10}$$

where q_{jmt} is firm j's optimal production at time t.

The parameters characterizing shipyards' production costs are $\theta^q \equiv \{\beta_{0m}, \beta_{sm}, \beta_{qm}, \sigma_{\omega m}\}_{m=1}^{M}$. We estimate these parameters via a Tobit model:

$$L = \prod_{m=1}^{M} \prod_{j,t;q_{jmt}=0} Pr(q_{jmt} = 0 | s_{jt}; \theta^q) \prod_{j,t;q_{jmt}>0} f_q(q_{jmt} | s_{jt}; \theta^q)$$

Note that the MLE estimate of θ^q is consistent even if ω_{jmt} is correlated over time, despite the fact that the likelihood function assumes (erroneously) ω_{jmt} is i.i.d. (Robinson, 1982).[19] To obtain the standard errors allowing for autocorrelation in ω_{jmt}, we use 500 (firm-block) bootstraps. Moreover, an implicit assumption of the Tobit estimation is that ω_{jmt} is independent of the price P_{mt}. This could be violated if favorable shocks lead to high production and affect ship prices. We allow ω_{jmt} to be correlated with P_{mt} in robustness analyses in Section 5.4.

Finally, a firm's production decisions provide no information on the fixed cost c_0 (costs of land usage, capital maintenance, etc.) since the firm incurs this regardless of whether it produces. Unlike most empirical studies where fixed costs are assumed away, we take advantage of the reported accounting cost data to calibrate c_0 (which existed even when the production facility is idle), see Appendix B.1. Restricting the fixed cost to zero may bias the counterfactual analyses (Aguirregabiria and Suzuki, 2014;

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[18] Large firms are defined as the set of firms that account for 90% of aggregate industry revenue in our sample period. Fifty-five Chinese shipyards are large. This variable (on top of capital and other firm attributes) captures unobserved differences across firms, like management skills and political connections, and improves model fit.

[19] Intuitively this is similar to how the OLS estimator in the standard linear regression model continues to be consistent (though not efficient) when the errors are non i.i.d.

Kalouptsidi et al., 2021); we discuss this issue in Section 6.1.

4.2 Estimation of Dynamic Parameters

We use observed firm-level investment, entry, and exit to estimate dynamic parameters. An important complication is that firms' optimal choices depend on the value function (as well as unobserved cost shocks for investment), which is unknown. To tackle this challenge, we follow the tradition of Hotz and Miller (1993) and Bajari et al. (2007) (henceforth BBL) and estimate the parameters in two stages. In the first stage, we flexibly estimate investment and exit policy functions, as well as the transition process of state variables from the data. Then, we use these estimates to obtain a flexible approximation of the value function. We approximate the value function by a set of B-spline basis functions of state variables, following Sweeting (2013) and Barwick and Pathak (2015). In the second stage, we formulate the likelihood of the observed investment and exit and recover the dynamic parameters of interest.

4.2.1 First Stage

Exit Policy Function We perform a probit regression, though results are robust to alternative specifications:

$$Pr(\chi_{jt} = 1|s_{jt}) = \Phi(h(s_{jt}))$$

where χ_{jt} equals 1 if firm j exits in period t, $h(s_{jt})$ is a flexible polynomial of the states, and Φ is the normal distribution. We denote the first-stage estimate of the exit probability by $\hat{p}^x(s_{jt})$.

Investment Policy Function The optimal investment policy function $i^*_{jt}(s_{jt}, \nu_{jt})$ is implicitly defined by the first order condition in equation (6). Our goal is to flexibly estimate $i^*_{jt}(s_{jt}, \nu_{jt})$. Under reasonable assumptions, one can show that the optimal investment is monotonically decreasing in ν_{jt}: firms with more favorable (smaller) cost shocks invest more, all else equal.[20] As a result, conditioning on s_{jt}, the jth quantile of ν_{jt} corresponds to the $(100 - j^{th})$ quantile of i_{jt}. As shown in Bajari et al. (2007), we can recover the optimal investment policy function $i^*_{jt}(s_{jt}, \nu_{jt})$ as follows:

$$\begin{aligned} F(i|s_{jt}) &= Pr(i^*_{jt} \leq i|s_{jt}) = Pr(\nu_{jt} \geq i^{*-1}(s_{jt}, i)|s_{jt}) = Pr(\nu_{jt} \geq \nu|s_{jt}) \\ &= 1 - F_\nu(\nu|s_{jt}) = 1 - F_\nu(\nu) \\ \text{which implies} \qquad i^*|s_{jt} &= F^{-1}\big(1 - F_\nu(\nu)\big) \end{aligned} \tag{11}$$

where $F(i|s_{jt})$ denotes the empirical distribution of investment given the state variables and $F_\nu(\nu|s_{jt})$ is the distribution of ν conditional on state variables. The data requirement for estimating this conditional distribution non-parametrically increases dramatically with the number of state variables. We make the

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[20] One sufficient condition for monotonicity is that the value function has increasing differences in investment and the negative of the investment shock.

simplifying assumption that the investment cost shock ν_{jt} is independent of observed state variables s_{jt} and enters additively in the investment policy function:

$$i_{jt}^{*}=h_1(s_{jt})+h_2(\nu_{jt}) \tag{12}$$

where both $h_1(s_{jt})$ and $h_2(\nu_{jt})$ are unknown functions to be estimated. Moreover, since the distribution of ν_{jt} cannot be non-parametrically identified from $h_2(\nu_{jt})$, we assume that ν_{jt} is drawn from a standard normal. We flexibly regress investment on state variables to obtain an estimate of $h_1(s_{jt})$. Then we treat $i_{jt}^{*}-\hat{h}_1\left(s_{jt}\right)$ as the relevant data and estimate function $h_2(\cdot)$ using equation (11).[21]

State Space The vector of state variables s_{jt} is a high-dimensional object because of the large number of firms in the industry. To reduce the computational burden, we assume that firms do not keep track of the state variables of every rival and use industry-level prices as a sufficient statistic (our estimates in Section 5.1 suggest that market power is limited). This approach is similar to the oblivious equilibrium concept in Weintraub et al. (2008) and Benkard et al. (2015) that approximates the Markov Perfect Equilibrium in industries with many firms. These techniques have been utilized in many recent empirical papers.[22]

We utilize the fact that a number of state variables enter the firm's marginal cost linearly and collapse them into a one-dimensional index, $\bar{s}_{jt}=-\sum_m s_{jmt}\hat{\beta}_{sm}$, using the estimated production cost coefficients. This index measures firms' observed cost efficiency: a higher $\bar{s}_{jt}$ is associated with a lower marginal cost and a higher variable profit.[23]

State Transition Process Some state variables, such as the province and ownership status, are fixed over time. Age increases are deterministic. Capital (k_{jt}) depreciates at a common rate δ: $k_{jt+1}=(1-\delta)k_{jt}+i_{jt}$. We calibrate δ to 2.3% quarterly (Brandt et al., 2012), reflecting China's high interest rates over our sample period. The steel price, which is perceived as exogenous to the industry, follows an AR(1) process. The equilibrium price for each ship type is a complicated object, determined by the aggregate demand and supply. We model ship prices as separate AR(1) processes, a behavioral assumption common in the literature (Aguirregabiria and Nevo, 2013). Government policies present a permanent and unanticipated shock to the industry, which potentially affects the evolution of prices. To capture this, we allow the AR(1) process for ship prices to differ before and after 2006 when the policies came into effect.

Value Function Approximation Armed with estimates of the policy functions and state transitions, we turn to the value function. The scrap value ϕ_{jt} is distributed exponentially with parameter $1/\sigma_{\phi}$. Hence,

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[21] We drop 5% outliers with investments exceeding RMB 250 million or capital stocks exceeding RMB 4 billion. Appendix B.2 performs robustness checks using Tobit and the Censored Least Absolute Deviation estimator (CLAD).

[22] See Huang et al. (2015), Sweeting (2015), Gerarden (2017), Jeon (2018) and Chen and Xu (2018).

[23] Using type-specific cost indices $\bar{s}_{jmt}=-s_{jmt}\hat{\beta}_{sm}, m=1,2,3$ instead of one index $\bar{s}_{jt}$ leads to similar dynamic parameter estimates. This is because firms that are better at producing one ship type are generally better at producing other ship types as well, and $\bar{s}_{jt}$ (with other state variables) approximates the value function well. See Appendix B.3.

the ex-ante value function (prior to the realization of ϕ_{jt}) is:

$$\begin{aligned} V(s_{jt}) &\equiv \mathbb{E}_{\phi} V\left(s_{jt}, \phi_{jt}\right) = \mathbb{E}_{\phi}\left[\pi(s_{jt}) + \max\left\{\phi_{jt}, CV(s_{jt})\right\}\right] \\ &= \pi(s_{jt}) + p^{x}(s_{jt})\mathbb{E}\left(\phi_{jt}|\phi_{jt} > CV\left(s_{jt}\right)\right) + \left(1 - p^{x}(s_{jt})\right) CV(s_{jt}) \\ &= \pi(s_{jt}) + p^{x}(s_{jt})\sigma_{\phi} + CV(s_{jt}) \end{aligned} \tag{13}$$

where $\mathbb{E}(\phi|\phi > CV) = \sigma_{\phi} + CV$ (Pakes et al., 2007). $\pi_{jt}(s_{jt})$ and $p^{x}(s_{jt})$ denote firms' static profit and exit probability, respectively, and $CV(s_{jt})$ denotes the firm's continuation value as defined in equation (4). We use B-spline basis functions to approximate the ex-ante value function, a smooth function that in theory can be approximated arbitrarily well (see further details in Appendix B.3).

4.2.2 Second Stage

Investment and Exit The dynamic parameters are $\theta^{i} \equiv \left\{\sigma_{\phi}, c_1, c_2, c_3\right\}$. We allow the linear component of investment costs, c_1, to differ before and after every policy period to capture the investment subsidies. We estimate θ^{i} via MLE, where the sample likelihood includes the likelihood for both exit and investment decisions. The log-likelihood for exit is:

$$\sum_{j,t} \log(f(\chi_{jt})) = \sum_{j,t} \left[(1 - \chi_{jt}) \log(1 - e^{-\frac{CV(s_{jt};\gamma)}{\sigma_{\phi}}}) - \chi_{jt} \frac{CV(s_{jt};\gamma)}{\sigma_{\phi}} \right]$$

where $\chi_{jt} = 1$ if firm j exits in period t.

Optimal investment $i^{*}_{jt} = i^{*}(s_{jt}, \nu_{jt})$ is defined by the first order condition in (6). By construction, when $i^{*}(s_{jt}, \nu_{jt})$ is positive, it is strictly monotonic in ν_{jt}. Assuming it is also differentiable, the likelihood of investment can be written as:[24]

$$g(i_{jt}) = \begin{cases} \frac{f_{\nu}(\nu_{jt})}{|i'(\nu_{jt})|} & \text{if } i^{*}(s_{jt}, \nu_{jt}) > 0 \\ Pr\left(\left[\beta \frac{\partial \mathbb{E}\left(V(s_{jt+1};\gamma)|s_{jt}, i\right)}{\partial i} - \frac{\partial C^{i}(i, s_{jt}, \nu_{jt})}{\partial i}\right]_{i=0} \leq 0 \right) & \text{if } i^{*}(s_{jt}, \nu_{jt}) \leq 0 \end{cases}$$

where in the first row, $f_{\nu}(\nu_{jt})$ is the density of cost shock ν_{jt} and $|i'(\nu_{jt})|$ is the absolute value of the derivative of $i^{*}(s_{jt}, \nu_{jt})$ with respect to ν_{jt}.

Since the scrap value ϕ_{jt} and investment shock ν_{jt} are assumed independent, the joint log-likelihood for exit and investment is the sum of the two respective log-likelihoods. We maximize the sample log-

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[24] The necessary condition for differentiability is that the value function is twice differentiable in investment, which holds since the value function is approximated by smooth spline basis functions.

likelihood subject to the Bellman equation (13):

$$\begin{aligned} \max_{\theta^i} L &= \sum_{j,t} log(f(\chi_{jt};\theta^i)) + \sum_{j,t} log(g(i_{jt};\theta^i)) \\ \text{s.t.} \quad V(s_{jt};\theta^i) &= \pi(s_{jt}) + p^x(s_{jt})\sigma_\phi + CV(s_{jt};\theta^i) \end{aligned} \tag{14}$$

Entry Cost Parameters Estimating the distribution of entry costs is straightforward once the investment cost and scrap value parameters are known. Upon entry, an entrant is endowed with capital that is drawn from the observed distribution of initial capital stocks. The cost of the initial capital equals $C^i(k_{jt+1}, s_{jt}) = c_1(s_{jt})k_{jt+1}$, which is the same as the cost of investment, except that there are no adjustment costs. We first construct the value of entry $VE(s_{jt})$ by plugging in dynamic parameter estimates and then estimate the mean entry costs using equation (8) via MLE. We do this separately before and after each policy period for each region, in order to capture the effect of entry subsidies (which differ across regions) that shift the mean of the entry cost distribution.

5 Results

This section follows closely the sequence in Section 4. Section 5.1 presents results on static parameters (demand and production costs). Section 5.2 discusses policy functions and the state transition process. Section 5.3 reports dynamic parameter estimates (investment cost, scrap values, as well as entry costs). Section 5.4 evaluates robustness. All costs (production costs, investment costs, and entry costs) are in real terms and measured in 2000 RMB. Appendix C provides more details.

5.1 Static Parameters

Demand Table C4 reports estimates of the demand curve (9). All variables have the expected sign and the effects are significant both economically and statistically. For example, demand for all ship types increases with freight rates. Demand is also responsive to backlog (which affects the future competition that shipowners face): a 1% increase in the backlog leads to a 1% decrease in the quantity of new ships demanded. According to our preferred specification (Column 2), the price elasticity was 1.8 for bulk carriers and tankers, 3.4 for containerships prior to 2006 and became somewhat less elastic afterwards.[25]

Production Costs Table 2 shows the estimated marginal cost parameters for Chinese yards for each ship type (standard errors are computed from 500 firm-block bootstrap simulations). Marginal costs are measured in 1000 RMB per CGT. The key parameters that characterize the curvature of production cost are type-specific (the coefficients on quantity, capital, backlog, and steel price), but coefficients on

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[25] Note that our preferred specification in Column 2 does not include a trend, which would make the dynamic model nonstationary.

subsidy dummies and shipyard attributes are restricted to be the same across ship types to reduce the number of parameters. There are intuitive reasons for these restrictions. The benefit of scale economies from holding a large backlog, the return to capital (which proxies for capacity), and input intensity are likely to be different across ship types. On the other hand, the effect of subsidies on production costs is probably similar across types, as subsidies are not earmarked by ship type, and firms can produce different ships depending on prevailing market conditions.

As China's policies came into effect in 2006 and underwent major changes in 2009, we allow production subsidies to be different between 2006-2008 and from 2009 onwards. The production subsidy is estimated to be 2,100 RMB/CGT between 2006-2008, which is 14-18% of the average price. The subsidy from 2009 onwards is smaller, at 1,220 RMB/CGT.[26] Though our estimation method, sample period, and industry coverage are different from Kalouptsidi (2018), the estimated subsidy is of a similar magnitude (with ours being slightly smaller), which is reassuring. Robustness exercises in Section 5.4 suggest that subsidy estimates remain similar in a DID framework that compares China to its competing countries and are robust to additional controls and different sample cuts, alleviating the concern of confounding factors that affect the industry cost structure. Although this approach of estimating subsidies has its own caveats, it is likely the only feasible strategy next to observing the subsidies directly.

The parameter β_q captures the increase in marginal cost (in 1000 RMB/CGT) from taking an additional order of 100,000 CGT. The larger β_q is, the more convex the cost function is, and the less responsive supply is to price changes. On average, a 10% price increase causes bulk carrier production to increase by 22%, tanker production by 27%, and containership production by 20%. Higher capital is associated with a lower marginal cost of production, though at a diminishing rate (the coefficient on capital squared is positive). Increasing capital by RMB 100 million for an average firm with a capital of RMB 400 million reduces marginal cost of production by 2.7% for bulkers, 2.2% for tankers, and 2.2% for containerships. To put these numbers into context, the average firm's per-period profits would decline by 19% if its capital stock were halved.

There are economies of scale in production with respect to the backlog: it is cheaper to produce multiple ships at the same time. The effect of backlog on marginal cost is sizable: increasing backlog by 100,000 CGT reduces marginal cost of production by 13% to 30% on average across ship types. As backlogs continue to increase, capacity constraints drive up marginal costs, as reflected in the positive coefficient (though smaller in magnitude) on backlog squared. Firms located in Jiangsu, Liaoning, and Zhejiang provinces (the major shipbuilding regions) have lower marginal costs, by 20-26% for Jiangsu, 14-18% for Liaoning, and 11-14% for Zhejiang. As shipyards age, their marginal cost increases by 1% each year. The effect of ownership is limited and statistically insignificant. Increases in steel prices raise marginal costs for all types, as expected.

Market power distortions are limited. The average markup for bulk carriers is 6.39% of new ship

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[26] Strictly speaking, these estimates reflect the pre- and post-2006 differences in subsidies. Our understanding is that production subsidies prior to 2006 were limited. Labor costs in China's manufacturing industry have been rising during the sample period (source: `https://www.bls.gov/fls/china_method.htm`). Controlling for labor costs leads to similar though slightly bigger subsidy estimates, reflecting the modest cost share of labor at around 10-20%.

prices and even lower for tankers and containerships. As a result, firms' production decisions are not far from setting marginal cost equal to the market price, suggesting that the industry is close to competitive.

Finally, the fixed cost calibrated from accounting data equals RMB 15 million per quarter, equivalent to 12% of the industry profit on average. Hence, setting it to zero, as is commonly done in the literature, would significantly overestimate per-period profits accruing to firms.

5.2 Dynamic Parameters: First Stage

Investment Policy Function Table C5 reports estimates for the investment policy function using OLS, Tobit with $h_2(\nu)$ normally distributed, and the Censored Least Absolute Deviation estimator that does not impose a distributional assumption on the cost shock and estimates $h_2(\nu)$ non-parametrically. Our preferred specification is OLS, which delivers the highest model fit. Investment increases in ship prices and decreases in steel price. Firms with higher $\bar{s}_{jt}$ (more productive) invest more all else equal. As expected, coefficients for both the 2006-08 and 2009+ policy dummies are positive. Moreover, investment is hump-shaped in the capital: it initially increases in capital stock, reaches a peak when capital is between RMB 1-1.5 billion, and then falls.

Exit Policy Function We estimate the exit policy function via Probit. Table C6 presents two sets of estimates using linear terms of all states as well as capital squared, with and without region fixed effects. Firms with higher $\bar{s}_{jt}$ are less likely to exit, which is intuitive as $\bar{s}_{jt}$ is a measure of firm profitability. Exit probabilities are lower when subsidies are in place.

5.3 Dynamic Parameters: Second Stage

Investment and Exit Table 3 reports the investment cost estimates.[27] Between 2006-2008, the subsidy was 0.27 RMB per RMB of investment, implying that 27% of the per-unit cost of investment (excluding adjustment costs) is subsidized. Post 2009, the subsidy jumps to 0.46 RMB per RMB of investment, which helps rationalize the elevated investment post the financial crisis with plummeting ship prices. In addition, the increase in subsidies post 2009 is consistent with the government policy change that shifted the focus towards consolidating the industry and supporting existing firms.

The coefficient on quadratic investment, c_2, is both economically and statistically significant. On average, adjustment costs account for 28% of total investment costs and exceed 50% for large investments over RMB 50 million. The large estimate of c_3 reflects the importance of firm-level unobserved investment shocks. Finally, average scrap value is estimated to be RMB 0.98 billion. This is significantly lower than the estimated value of a firm, $V(s_{jt})$, which is around three to four billion RMB, as exit is a rare event and occurs in only 1% of the observations.

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[27] The linear investment cost coefficient is equal to $c_1(s_{jt}) = 1 + \gamma_1 * 1\{2006 - 2008\} + \gamma_2 * 1\{2009+\}$, where we assume that the unit investment cost is equal to 1, following the empirical literature on investment (Cooper and Haltiwanger, 2006). Monte Carlo evidence indicates that it is difficult to identify this parameter.

Figure C3 plots the distribution of the observed and model-predicted investment. They are reasonably similar, though actual investment has a longer tail of large investments and fewer medium-sized ones. Table C8 compares the actual number of exits with the model's estimates. Firm exits are low-probability events and in general difficult to predict (Goldfarb and Xiao, 2016). Our model roughly matches the sample mean but under-predicts the number of exits post 2006.

Entry Cost Estimates The number of entrants is quite different across provinces, with Zhejiang having the highest number of entrants at 95 during the sample period and Liaoning, Jiangsu, and Zhejiang collectively accounting for 70% of new shipyards. We estimate the entry cost separately for Liaoning, Jiangsu, Zhejiang, and the rest of China.[28] We also allow the entry cost to differ across policy periods. Table 4 reports estimates for the mean entry costs for period before 2006, between 2006 and 2008, and post 2009 respectively. In light of the unprecedented entry boom from 2006 to 2008, it is unsurprising that we find substantial entry subsidies, with the fraction of entry costs that is subsidized varying from 51% in Liaoning to 64% in Jiangsu. Entry costs increased substantially in 2009 when the entry moratorium was put in place. Conditional on entering, the average entry cost paid is RMB 2.5 billion, close to a shipyard's accounting value.[29] Our estimated number of entrants is reasonably close to the actual number in each policy period (Table C9).

5.4 Robustness

The baseline specification estimates production costs separately for each country. Table C11 pools shipyards from all three countries, which amounts to a DID estimator. As we do not observe capital for Japanese and South Korean shipyards, we set their capital stock to zero and add country dummies. Results are qualitatively similar to the baseline, though the 2006-08 subsidy is somewhat larger. We prefer the baseline specification, which allows more flexibility in capturing production differences across countries and delivers a more conservative estimate of the subsidy magnitude.[30]

Next, we explore whether there is evidence of learning-by-doing among Chinese shipyards (Benkard, 2004). We examine both within-firm and industry-wide learning-by-doing by allowing the marginal cost of production to depend on firms' past production and industry cumulative past production. The results are presented in the second the third panels in Table C11. There is no evidence of either type of learning-by-doing: marginal costs tend to increase rather than decrease in past production. This is consistent with industry reports that the technology for producing bulk carriers and tankers has been around for decades and is mature. Past studies documenting learning-by-doing in shipbuilding (Thompson, 2001; Thornton and Thompson, 2001; Hanlon, 2020) provide mixed evidence on learning spillovers across

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[28] Entry subsidies are assumed to begin in 2004 for Zhejiang, when it identified shipbuilding as a pillar industry, and in 2006 for all other provinces. The observed entry peaked earlier in Zhejiang than the rest of the country.

[29] The average entry cost conditional on entering is given by $\mathbb{E}(\kappa_{jt}|\kappa_{jt} \leq VE(s_{jt}))$. See `http://www.jiemian.com/article/1483665.html` and `http://www.wuhu.com.cn/compay_mod_file/news_detail.php?cart=3&id=595` for news articles that report the book value of shipyards.

[30] Using cost estimates that pool data from all three countries leads to qualitatively similar counterfactual results.

firms. Thompson (2001) attributes half of the previously documented learning-by-doing in US naval shipyards during the World War II to capital expansion, while Thornton and Thompson (2001) show that the size of learning externalities among these shipbuilders is small.

Incorporating a time trend or excluding new shipyards that entered after the policy announcement (which might have newer and better technologies) leads to similar results (Table C12). We have estimated production subsidies separately for each region. They are higher in Jiangsu and Liaoning than in Zhejiang and the rest of China, although the differences are statistically insignificant. While in principle production cost estimates depend on demand elasticity, in our setting they are robust to demand parameters largely because markups are modest.

The production analyses so far assume that firms' production cost shocks are independent of ship prices. This could be violated if favorable shocks lead to high production and affect ship prices. In Appendix C.5, we deal with this endogeneity problem by allowing the cost shocks to be correlated with ship prices and using a control function approach (MacKinnon and Olewiler, 1980; Smith and Blundell, 1986; Newey, 1987; Chernozhukov et al., 2015). The cost estimates are similar to our baseline results. Moreover, the estimated correlation between production cost shocks and residuals of prices (after partialling out controls) is small and varies between 0.002 and 0.05 in absolute value across ship type. These results suggest that the rich aggregate controls in our cost specification minimize the potential for correlation.

A common challenge in estimating entry costs is that the number of potential entrants $\bar{N}$ is inherently unobserved. Our baseline assumes that the number of potential entrants in a region in any quarter is twice the maximum number of observed entrants in that region, following the literature (Seim, 2006). We have estimated the entry cost under alternative assumptions (e.g. the maximum number of entrants ever observed, or a large number such as 20 and 40). While a higher number of potential entrants leads to a higher estimate of κ_{jt}, the estimated entry cost paid upon entering and entry subsidies are remarkably robust as they are determined by the actual number of entrants and the value of entry (which is estimated using observed ship prices and firm production). Finally, Appendix Section B.3 and Section C report more details and additional robustness analyses.

6 Evaluation of China's Industrial Policy in Shipbuilding

Like other countries that use industrial policies to promote specific sectors (Krugman et al., 1983; Lane, 2022), China adopted a variety of policy instruments to boost the shipbuilding industry's output. Moreover, the policy implementation underwent significant changes over time. Early on, subsidies were widely accessible to all firms. In later years, the government shifted support towards SOEs and established firms (the White List), while curbing the entry of new firms.

In this section, we evaluate the long-term implications of China's industrial policy. Our goal is to assess the relative performance of different policy instruments, taking into account the critical role played by firm heterogeneity, dynamics and business cycles. Specifically, we address the following questions:

(i) which policy instruments are the most effective; (ii) how should industrial policy be designed in the presence of industry fluctuations and business cycles; (iii) what are the consequences of targeting subsidies toward selected firms through consolidation policies?

Evaluating the industrial policy's long-term impact necessitates simulating the world shipbuilding industry for a long period of time, as both entry and investment have dynamic consequences – the accumulated capital remains productive long after the policy ends.[31] Our simulation begins in 2006, when the Chinese government started subsidizing its domestic industry, and ends in 2050, a period long enough to evaluate a policy's dynamic impacts, though results are similar if longer horizons are used. In each counterfactual scenario, we turn on and off the subsidies as needed and report the industry average over 50 independent simulations (results are nearly identical with 100 simulations). Chinese firms make production, investment, exit, and entry decisions. Japanese and South Korean firms choose production. Equilibrium prices are determined by the intersection of the industry demand and supply curves. All monetary values, including industry revenues and total subsidies, are discounted (at a quarterly rate of 2%) and measured in the 2000 constant RMB.

Section 6.1 quantifies how the policy affected the actual evolution of the global industry between 2006 and 2013. Section 6.2 assesses the long-term performance of different policy instruments. Section 6.3 discusses various aspects of policy design, such as the timing of subsidies, targeting, and policy duration. Appendices D.1 and D.2 contain more details on implementation and Appendix D.3 reports additional counterfactual results.

6.1 Impact on Industry Evolution

Perhaps not surprisingly, the Chinese government's subsidies had a significant impact on the evolution of every outcome of interest: China's market share, total ship production, ship prices, entry and exit, investment, profits, industry concentration and capital utilization.

According to our estimates, total (discounted) subsidies handed out to Chinese shipbuilders between 2006 and 2013 were close to RMB 624 billion ($91 billion), which can be broken down into entry subsidies (RMB 431 billion), production subsidies (RMB 156 billion) and investment subsidies (RMB 37 billion).[32] These subsidies are massive in comparison to the size of the domestic industry, whose revenue was around RMB 1360 billion during the same period.

Government support increased China's world market share during 2006-13 by 42%. The ascent in market share is most pronounced for bulk carriers, since a large fraction of new shipyards produce bulk carriers, and Japanese and South Korean firms' cost advantage is narrower for bulk.

In absolute terms, only 30% of China's increased production translated into higher world output. The remaining 70% constitutes business-stealing, whereby Chinese production expanded at the expense

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[31] Production subsidies also have dynamic consequences through backlogs that affect future costs of production, though these effects disappear within a few years when backlogs are converted to deliveries.

[32] While entry subsidies are large in magnitude, they are consistent with a back-of-the-envelope calculation: entry subsidies induced the entry of 80 additional firms and each firm is worth a few billion RMB.

of competing firms in other countries. Chinese subsidies reduced South Korea's world market share from 48% to 39% and Japan's market share from 23% to 20% during 2006-2013, with profits earned by shipyards in these two countries falling by RMB 144 billion. Despite the rising market share of Chinese shipyards, their gains in gross profit (revenue minus production costs) in this period are a modest RMB 153 billion, as the output expansion was largely fueled by the entry of inefficient firms.

The subsidy-induced rising global supply led to a substantial reduction in global ship prices: the price of bulk carriers, oil tankers, and containerships fell by 9.9%, 10.1%, and 4.3% from 2006 to 2008, respectively (Table D14). As the impact of past subsidies accumulated over time, the price drop became more pronounced post 2009 and reached 16.8% for bulk carriers, 14.8% for tankers, and 4.2% for containerships. The price effect is the most significant for bulk carriers because Chinese shipyards account for a bigger market share and demand for bulk carriers is less elastic. Lower ship prices benefited world shipowners by RMB 290 billion, though only a modest amount accrues to Chinese shipowners as they account for a small fraction of the world fleet.[33]

Figure 2 illustrates the striking effect of subsidies on investment, which skyrocketed post 2006. Total investment during 2006-2013 is RMB 80 billion with subsidies, compared to RMB 33 billion without subsidies. Figure 3 examines the effect on the number of Chinese firms. Government support more than doubled the entry rate: 143 firms entered with subsidies vs. 64 without subsidies from 2006 to 2013. It also depressed exit (38 firms exited vs. 43 without subsidies).

Finally, the policy led to increased fragmentation. Entry subsidies induce entry of small inefficient firms. Production and investment subsidies boost firms' variable profit and retain unprofitable firms that should have exited. China's domestic Herfindahl-Hirschman index (HHI) plummeted from 1,200 in 2004 to less than 500 in 2013 with a significantly lower 4-firm concentration ratio (Figure D4). Despite a sizable increase in China's overall production, capacity utilization was much lower, particularly when demand was low post 2009. If China had not subsidized the shipbuilding industry, the ratio of production to capital (which proxies for capacity utilization) would have been 19% higher during the 2009-2013 recession.

6.2 Long-term Performance of Policy Instruments

We carry out five counterfactual exercises with different subsidies in place: all subsidies (as in the data), only production subsidies, only investment subsidies, only entry subsidies, and no subsidies. We assume that the 2013 policy environment is propagated to the end of our simulation period. For example, in the scenario with all subsidies, entry subsidies run from 2006 to 2008, whereas production and investment subsidies run from 2006 to 2050. Since China's domestic consumer surplus is modest compared to the industry profit as discussed earlier, we focus on industry outcomes, such as output and profits, in our discussion below.[34]

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[33] Orders by Chinese shipowners were growing but accounted for under 10% of world orders in 2010-2013 (Clarkson World Shipyard Monitor).

[34] Incorporating consumer surplus enjoyed by Chinese shipowners increases the gross rate of return from 18% to 24%.

Table 5 reports the discounted sums of long-term industry revenue and profit for Chinese shipyards, as well as the magnitude of different subsidies. The last two rows, "ΔRevenue/Subsidy" and "ΔNet Profit/Subsidy", constitute different measures of policy effectiveness. "ΔRevenue" is the revenue difference between the scenario with subsidies and the scenario without subsidies. The ratio between increased revenue and subsidy cost reflects a policy's effectiveness on promoting industry revenue. This is of interest, as China's official government documents explicitly state production targets for the domestic shipbuilding industry. "ΔNet Profit" is the difference in net profit which equals revenue plus the scrap value upon exiting, minus the costs of production, investment, and entry. "ΔNet Profit/Subsidy" measures the gross rate of return. A rate lower than 100% indicates that the cost of subsidies exceeds the net benefits to the domestic industry.[35]

Comparison of Different Policy Instruments When all subsidies are in place, the policy mix is highly ineffective, as reflected by the rate of return being merely 18%. When each policy is in place in isolation, the return is 50% for production subsidies, 74% for investment subsidies, and 32% for entry subsidies, respectively. Thus, entry subsidies are substantially less effective than production and investment subsidies (more on this below). In addition, the distortions induced by multiple subsidies are convex: the combination of all policies yields a considerably lower return compared to each policy in isolation. Entry subsidies lower the entry threshold and thus attract inefficient entrants. With the introduction of production and investment subsidies, the number of firms in operation is further inflated due to subsidized revenue. This drives down the rate of return and makes the subsidies more distortionary in per-RMB terms.

An important factor contributing to the low returns is fixed costs. Firms incur fixed costs to stay in business even when they receive no orders from buyers. In volatile industries with cycles of booms and busts, this tends to be a common occurrence: firms are willing to suffer temporary losses and stay idle in anticipation of higher demand in the future (hysteresis). If fixed costs were zero, the rate of return on subsidies would increase from 18% to 25%.

We now turn to the performance of each type of subsidy in isolation. If industry revenue is the object of interest, both production and investment subsidies are effective. One RMB increase in either subsidy raises the industry's revenue by 1.5 RMB. This might justify the popularity of these subsidies in China, since quantity and revenue targets are often linked to local officials' promotions (Jin et al., 2005). Investment subsidies appear less distortionary than production subsidies (74% vs. 50%). Investment subsidies lead to a higher level of capital formation and facilitate long-term industry growth, while production subsidies have a more immediate impact on output (Table D15.)

Entry subsidies are the least effective policy instrument among the three by a large margin. They predominantly attract small and high-cost firms that would not find it profitable to enter in the absence of

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[35] The calculation here does not consider the cost to finance these subsidies. Estimates from Ballard et al. (1985) suggest that collecting 1$ of government revenue costs $0.17-$0.56 in the U.S. Including the cost to finance subsidies further drives down the rates of return. Another issue is that some "subsidies", such as simplification of the entry procedure, might not be financial. Appendix D.3 shows that this has a modest impact on policy returns.

subsidies (Table 2 shows that entrants, which are small in scale, are less efficient). In addition, the take-up rate for production and investment subsidies is much higher among firms that are more efficient: 82% of production subsidies and 68% of investment subsidies is allocated to firms that are more efficient than the median firm, whereas only 49% of entry subsidies goes to more efficient firms (Table D16). Furthermore, production and investment subsidies increase backlogs and capital stocks that lead to economies of scale and drive down both current and future production costs, a mechanism that is absent in entry subsidies.

The conclusion that entry subsidies are wasteful is driven by the observed data patterns. In addition to entrants being less efficient producers, compared to firms that existed before 2005, new entrants were more likely to be idle (74% vs 56%) and less likely to make investments (61% vs 72%). Many of these shipyards exited the market after the financial crisis. The number of active shipyards in China declined by almost 50% from its peak in 2009 to 2020 (Figure D5).

6.3 Policy Design

In this section, we turn to policy design and search for general lessons that can be applied in contexts outside China's shipbuilding industry, including counter-cyclical policies, filtering inefficient firms, and setting policy duration.

Business Cycles and Industrial Policy Like many other manufacturing industries, cycles of booms and busts are a fundamental feature of shipbuilding.[36,37] To explore whether the effectiveness of subsidies varies over the business cycle, we carry out two counterfactuals. The first subsidizes production and investment during the 2006-08 boom, while the second subsidizes production and investment during the 2009-13 bust. All subsidies are discontinued afterwards. The subsidy rates are calibrated so that government spending is identical in both scenarios.

Strikingly, subsidizing firms during the boom leads to a net return of only 38%, whereas subsidizing firms during the downturn leads to a much higher return of 70%, as shown in Table 6. What explains this large difference?

There are two main contributing factors to this finding: convex production and investment costs, and firm composition. In boom periods, the industry is operating close to full capacity. Further expansion is costly and entails the utilization of high-cost resources. Firms that are already producing and investing may choose to engage in more rapid expansion than is optimal, incurring large adjustment costs. During a bust, on the other hand, the industry operates well below capacity and many production facilities remain

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[36] The macro and public finance literature that explores optimal fiscal policies over the business cycle generally recommends counter-cyclical fiscal policies, in order to smooth out intertemporal consumption (Barro, 1979), reduce the efficiency costs of business cycle fluctuations (Gali et al., 2007), and increase long-term investment by lowering volatility (Aghion et al., 2014). It is less well-understood, however, how industrial policy should be designed in the presence of industry fluctuations.

[37] Business cycles themselves are not major causes of inefficiency. The subsidy return is slightly higher (23%) in Table D17 that uses the steady-state aggregate demand, compared to 18% in the baseline with a pronounced boom and bust cycle. This is because we control for the business cycles and aggregate demand shifters in simulations. The booms and busts only modestly exacerbate the low return due to the convexity of production and investment costs.

idle. Subsidies mobilize underutilized facilities, resulting in smaller distortions. The second contributing factor is the changing firm composition over the business cycle. Subsidies during a boom attract inefficient firms, which pushes down the rate of return. Figure 4 plots the average marginal cost index over time for both scenarios. Marginal costs are higher when subsidies are distributed during the boom than during the bust, as expected.

Despite the benefits of a counter-cyclical policy, the actual policy mix was overwhelmingly pro-cyclical: 90% of total subsidies was handed out between 2006 and 2008 vs. 10% between 2009 and 2013. This echoes a more general finding in the literature showing that developing countries typically use pro-cyclical fiscal policies (Frankel et al., 2014), due to budget constraints and political considerations (Tornell and Lane, 1999; Barseghyan et al., 2013).

Targeting Efficient Firms To facilitate consolidation and create firms that can compete against international conglomerates, China implemented *Shipbuilding Industry Standard and Conditions* in 2013 and periodically announced a list of firms that meet the industry standard, the "White List". We next evaluate whether and to what extent the consolidation policy and targeting improves the return of subsidies, as well as the government's actual choices of firms on the White List.

The first official White List consisted of 56 firms.[38] In our counterfactual exercise, we rank firms based on expected variable profits ($E[\pi_{jt}]$) in 2013, select 56 firms with the highest profitability to form the "optimal White List," and simulate the industry from 2014 to 2050. These firms receive production and investment subsidies, while other firms receive no subsidies post 2013. We compare this policy to a scenario that subsidizes all firms after 2013 and one with no subsidies.

As shown in Table D18, directing subsidies towards the best set of firms (the optimal White List) generates *considerable* gains. The net rate of return for targeted production and investment subsidies is 71%, whereas the return is 37% when all firms are subsidized. This pattern holds across both measures of policy effectiveness (revenue and net profit), due to several reasons. First, subsidizing all firms encourages sub-optimal entry, while the White List policy only subsidizes existing firms and does not distort entry. Second, firms on the White List have lower production costs; shifting support to more efficient firms reduces misallocation. Third, these firms are less prone to sub-optimal investment and production decisions than the average firm in the presence of subsidies.

China's actual White List appears to favor SOEs: 65% of firms selected by the government are SOEs, while 55% of our selected firms are SOEs. Out of the 56 firms chosen by the government, only 31 firms appear on our White List. Information asymmetries and regulatory capture might have biased the process in favor of interest groups (Lane, 2022).

Temporary Subsidies Our analyses above assume that the production and investment subsidies were long-term, as the subsidy program had no official end date and is still ongoing in some format today (e.g. shipbuilding was included in the latest program, "Made in China 2025"). Here, we examine how

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[38] We focus on 56 firms because four out of sixty firms on the 2014 White List cannot be matched to our datasets.

the policy would have performed if it were explicitly temporary in nature. We consider two types of policies: (i) a temporary policy where the government commits to phasing out subsidies by an end date T that is known to all firms; and (ii) a temporary targeted policy where the subsidies are temporary and targeted towards productive firms. This is similar to the "White List" policy that we examine above, but the subsidies are now temporary in nature. We contrast both policy designs against a permanent policy and the no-policy scenario, holding the government budget fixed among the three policies with subsidies.

We exclude entry subsidies, which are inefficient according to our analyses. Moreover, we implement these counterfactuals under a steady state demand. This is done on purpose to avoid the complications of whether the temporary subsidies coincide with a period of growth or recession, a topic that we examine in Section 6.2. Examining the effect of temporary subsidies introduces the methodological challenge that firms' value functions are non-stationary. Appendix D.2 describes how we address this.

Table 7 compares these three alternative policy designs. The rate of return on permanent industrial policy is 47%.[39] In contrast, making industrial policy temporary results in a higher rate of return at 55%. Temporary industrial policy that is *targeted* towards productive firms results in the highest rate of return at 75%. Two mechanisms make temporary industrial policy more effective: a selection effect and a scale effect; temporary and targeted policy further magnifies these two channels. Permanent subsidies encourage entry, discourage exit, overprotect inefficient firms, and result in a fragmented industry structure. Making subsidies temporary dampens these negative selection effects. Second, temporary policies entail larger subsidies per unit of production and thus augment the increasing returns to scale and lead to a much higher backlog per firm. As a result of these two channels, the average firm is significantly more cost-efficient, especially under the temporary and targeted policy, in both the medium-term and long run (Figures D6 and D7).

We also investigate the optimal duration of a temporary policy (Table E19). The rate of return is not always monotonically increasing as the horizon is shortened. A short-lived policy performs poorly, with little capital accumulation due to convex costs of investment. The optimal horizon in our context is between 3 and 5 years. In comparison, the actual policy implemented in China lasted more than a decade, although it underwent significant changes over time.

Summary Our results shed light on the underlying mechanisms for diverging outcomes across countries due to the timing of intervention, choice of policy instruments, the discriminatory nature of the policy, and policy duration. For instance, in East Asian countries where industrial policy is often regarded as successful, policy support was conditioned on performance, with non-performing firms penalized by the withdrawal of support. In contrast, in Latin America where the import-substitution policies were less effective and abandoned in the 1980s, there were no effective mechanisms to weed out non-performing beneficiaries (Rodrik, 2009).[40] Our analysis highlights that similar mechanisms are at work in China's

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[39] As this policy does not include entry subsidies, the return is substantially higher than the rate of return on the policy mix that China actually adopted (18%).

[40] Lack of policy evaluations in Latin American countries is a significant hindrance to this debate (Peres, 2013).

modern-day industrial policy in the shipbuilding industry. The policy's return was low in earlier years when output expansion was primarily fueled by the entry of inefficient firms, but increased over time as the government shifted support to more efficient firms and used 'performance-based' criteria (the White List) to channel subsidies.

A key insight from our analysis is that industrial policy is relatively more effective when it takes into consideration firm heterogeneity and the nature of business cycles, prioritizing support for efficient firms at times when economic expansion is not costly. Investment subsidies outperform entry subsidies in part because they are mostly taken up by more efficient firms that dominate investment activity. Similarly, counter-cyclical policy mobilizes underutilized resources and indirectly targets low-cost firms since these are the firms that are more likely to operate during a downturn. In addition, there are gains from consolidation and targeting, though as China's experience suggests, it can be difficult for the government to pick the most efficient firms.

7 Rationales for Industrial Policy

We now assess traditional arguments in favor of industrial policy and evaluate the extent to which the policy in the shipbuilding industry is effective in achieving these objectives. Appendix E provides greater details for each of the rationales we discuss here and more.

In the presence of market power, there are in principle strategic trade benefits from subsidizing industries that compete with foreign firms (Dixit, 1984; Krugman, 1986; Eaton and Grossman, 1986; Brander, 1995). For these considerations to be relevant, a necessary condition is the existence of substantial market power and thus 'rents on the table' that, when shifted from foreign to domestic firms, outweighs the cost of subsidies. To investigate this, we carry out a counterfactual simulation where firms are price takers in the product market, which eliminates any strategic trade motives behind industrial policy (Table E20.) The overall return of subsidies with perfect competition is lower than our baseline estimates, but the gap is modest (14% vs. 18%). The difference is mainly driven by production subsidies becoming less effective when firms are price takers (their return drops from 50% to 38%). These results suggest that market power considerations in the shipbuilding industry cannot justify the strategic trade arguments, consistent with results in Section 5.1 that markups are low.

Another justification for subsidies is the presence of positive externalities (such as industry-wide learning-by-doing), in which case each firm produces less than socially optimal. As discussed in Section 5.1, there is no evidence of significant spillover effects in this industry, corroborating industry reports that much of the production by Chinese shipyards occurs in product sectors with mature technologies where the scope for learning is limited.[41]

Industrial policies are often argued on the grounds of labor market consequences: subsidies could

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[41] There might be technological 'catching-up' and learning among Chinese shipyards for producing the latest generation ships (e.g. large containerships or LNG's), where most of the patents and 'know-how' are possessed by Japanese and South Korean firms. Unfortunately, there are few orders of these ships, and we cannot directly test this.

have welfare benefits if they increase employment or offset distortions that lead to depressed employment. Even in the grand scheme of things, total employment in shipbuilding and related industries (ship repairs, marine equipment, etc.) accounts for less than 0.1% of national employment, suggesting that any potential labor market benefits would be modest.[42]

There are potential spillovers to upstream sectors, as intermediate inputs from other sectors account for 50-60% of the value of ships and steel contributes to another 25-30% (Jiang and Strandenes, 2012). One might argue that shipbuilding subsidies are partially designed to boost demand for steel, a strategic sector that is subject to many policy interventions. However, steel used in shipbuilding accounts for less than 1.5% of total steel produced (China's 2012 Input-Output Table). Looking at downstream sectors, three-quarters of the output from this industry is used for final consumption. However, more than 80% of ships are exported, which limits the fraction of subsidy benefits that is captured domestically.

As pointed out by Hausmann and Rodrik (2003), developing countries often do not know which products they are good at producing. Some entrepreneurs incur the cost of setting up production and bear the risk of discovering products that a country is good at producing. Once this knowledge is known, it can be (sometimes quickly) imitated by followers. As a result, early entrepreneurs only capture a fraction of the social value they generate. The gap between the social and private benefits of exploration justifies government intervention, such as entry subsidies to promote entrepreneurship in the first place. Our analyses presented in Appendix E.2 indicate that cost discovery is unlikely to be important in our setting. There is no evidence that spillovers across firms or common cost shocks via cost discovery existed, firms benefited from rivals' past favorable cost shocks, or marginal costs of production decreased with the number of firms producing a ship type in the past.

Another motivation might be causing foreign firms to exit; then, if future entry is costly, China's policy could lock in a longer-term increase in market share. But only a small number of Japanese and Korean firms exited; altogether they accounted for 1.6% of global production (Appendix E.3). The additional business-stealing effect as a result of Chinese shipyards taking the place of these foreign firms is small compared to our baseline estimates, where China's world market share went up from 29% to 42%.

One rationale that might justify China's shipbuilding subsidies relates to the role of ships in international trade: a larger worldwide fleet reduces transportation costs (freight rates). As China became the world's biggest exporter and a close second largest importer in our sample period, transport cost reductions can lead to substantial increases in trade volume. To evaluate this argument, we carry out a back-of-the-envelope calculation of the subsidies' impact on China's trade volume in Appendix E.4. Subsidies reduced bulk carrier freight rates by 6.1% and containership freight rates by 2% between 2006 and 2013. Using trade elasticities from the literature (Brancaccio et al., 2020; Jeon, 2018), the industrial

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[42] According to OECD (2016), it takes eight worker-years in shipbuilding and 26 worker-years in upstream sectors to produce ships valued at $1 million in China. As 1 unit of production subsidy is associated with 1.5 units of revenue increase (Table 5), these numbers suggest that production subsidies of $1 million create 12 jobs in the shipbuilding sector and 39 jobs in upstream sectors for one year. Thus, subsidizing shipbuilding does not appear cost-effective to create jobs given China's GDP per capita at $2,099 in 2006 and $7,051 in 2013.

policy raised China's annual trade volume by 4.9% ($144 bn) between 2006 and 2013.[43] The increase in trade volume was large relative to the size of the subsidies (which averaged $11.3 bn annually between 2006 and 2013); however, calculating the welfare gains associated with the increased trade volume falls beyond the scope of this paper.

Outside economic considerations, national security and production of military ships might be another relevant factor. Data on military production is scant, and our analysis is incomplete in nature (presented in Appendix E.5).[44] The military production of naval ships is concentrated in thirteen subsidiaries of China State Shipbuilding Corporation (CSSC) and China Shipbuilding Industry Corporation (CSIC), the two largest conglomerate shipyards that are also state-owned. These subsidiaries are typically dual-use, producing both commercial and military ships in the same complex (Erickson, 2017).

Figure E9 plots the annual deliveries of naval and commercial ships from 2006 to 2013 for all Chinese shipyards (Panel a) and for the thirteen dual-use shipyards that produce both military and commercial ships (Panel b), respectively. Both types of deliveries experienced a several-fold increase during this period, although military production appeared to have accelerated after the financial crisis. Like the rest of the commercial shipyards, the dual-use shipyards also exhibited significantly higher production in both ship types, providing suggestive evidence that China's supportive policy might have benefited its military production as well. Due to the small number of observations and the difficulties in verifying data coverage, we take such evidence as suggestive.

Regardless of the motivation, our analysis evaluates various policy design considerations and the relative efficacy of different instruments that can be used as guidance for future policies.

8 Conclusion

Industrial policy, which until recently was considered old-fashioned, has reemerged in many regions around the world, including the EU and the US. Despite the strong interest from policymakers and economists alike, few studies have used firm-level data to examine the relative efficacy of different designs, as well as the long-term welfare implications of industrial policies.

We conduct such an analysis of China's industrial policy in the shipbuilding industry using firm-level data and a dynamic model of firms' entry and exit, production, and investment decisions. While subsidies significantly boosted China's world market share and buttressed China's ascent into global influence, they also exacerbated industry fragmentation and led to increased capacity idleness. The policy initially exhibited a low rate of return, though returns improved over time as the government shifted away from subsidizing all firms and adopted policies that better targeted efficient firms. An important insight from our study is that adopting counter-cyclical policies, targeting efficient firms, and intervening temporarily

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[43] For comparison, Ianchovichina and Martin (2004) estimate that China's accession to WTO led to a 40% increase in its trade volume.

[44] We thank Elliott Mokski for discovering and collecting data on military ship production from the annual report IHS Jane's Fighting Ships and Erickson (2017).

instead of long-term could significantly increase the effectiveness of industrial policies from a welfare perspective. Finally, when exploring possible objectives for China's industrial policy, we find support for non-classical rationales, such as bringing down freight rates to boost Chinese trade and suggestive evidence for military considerations.

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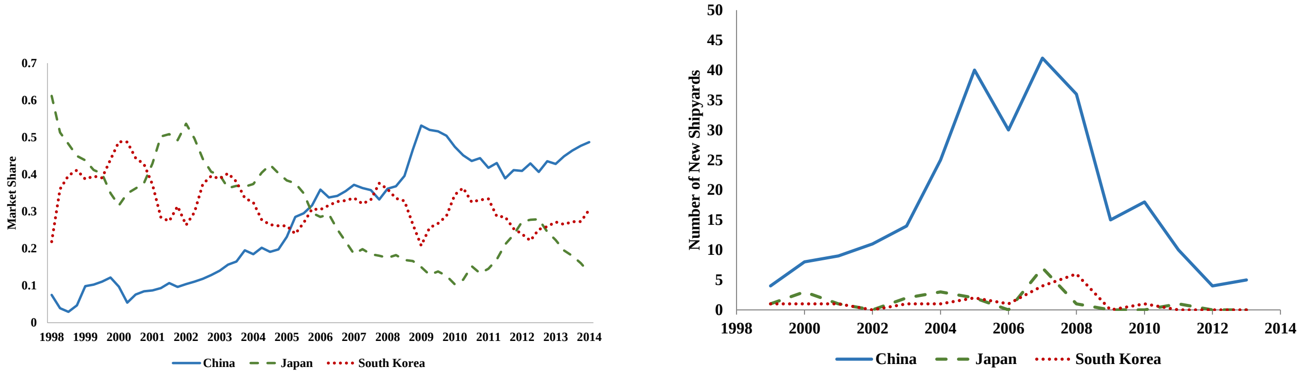
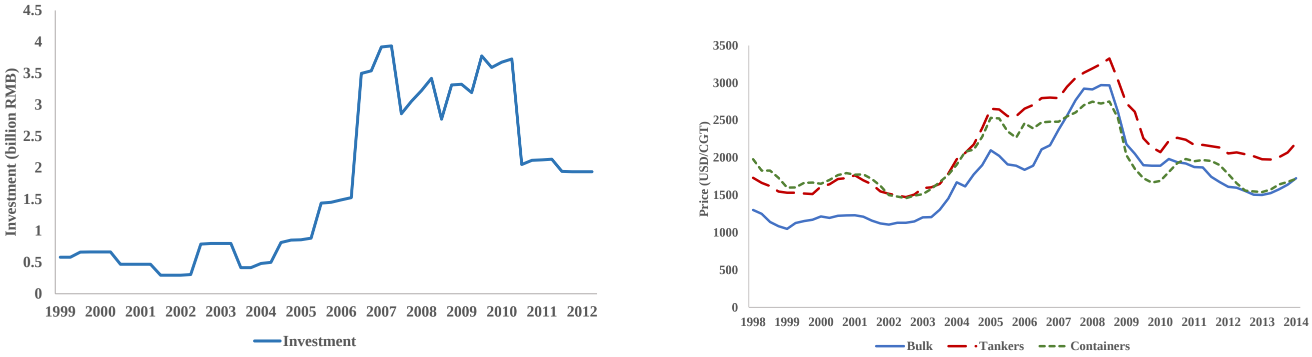
Figure 1: Evolution of the Shipbuilding Industry



(a) China's market share expansion

(b) Entry of New Shipyards by Country

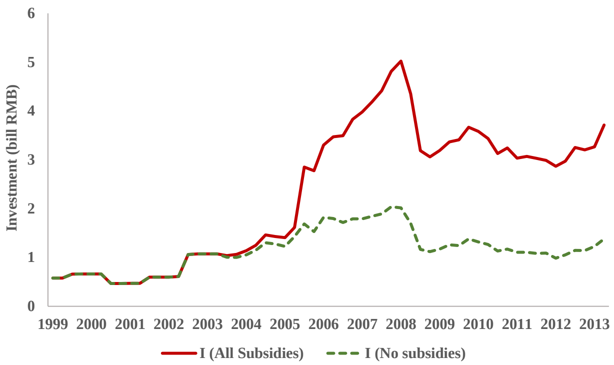


(c) Investment by Chinese Shipyards

(d) New Ship Prices

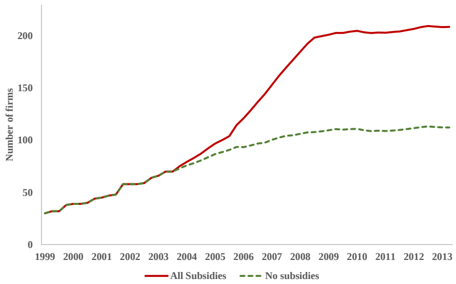
Figures (a) - (c) illustrate the rapid expansion of China's shipyard industry. a) Source: Clarkson Research. Market shares by country are computed from quarterly ship orders. b) Source: Clarkson Research. Number of new shipyards each year by country. c) Source: China's National Bureau of Statistics. Industry aggregate quarterly investment by Chinese shipyards in billions of 2000 RMB. Figure d) plots new ship prices (source: Clarksons Research). Average new ship price in nominal USD/CGT by ship type.

Figure 2: Investment, with and without Subsidies



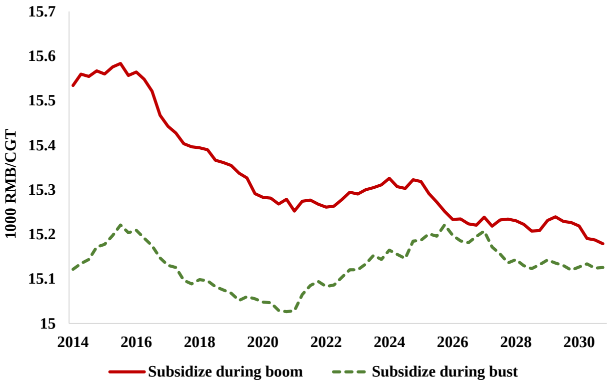
Note: Counterfactual results on total quarterly investment (in billions of 2000 RMB) with entry/production/investment subsidies (solid red line) and with no subsidies (dashed green line).

Figure 3: Number of Firms, with and without Subsidies



Note: Total number of firms in the case of all subsidies as observed in the data (solid red line) and counterfactual number of firms with no subsidies (dashed green line).

Figure 4: Marginal Cost Index with Subsidies During the Boom vs. Subsidies During the Bust



Note: The marginal cost index is defined as the portion of marginal cost determined by the firm's capital stock, backlog and other firm-level characteristics (such as age, size, and ownership status), $\bar{s}_{jt}$, and averaged across firms in thousands of 2000 RMB per CGT. The graph plots the average marginal cost index when subsidies are distributed during the boom of 2006-2008 (solid red line) vs. during the bust of 2009-2013 (dashed green line).

Table 1: Summary Statistics

Variable	Obs	Mean	S.D.	Min	Max
All Observations (including zero orders)					
Bulk carrier orders (1000 CGT)	10,101	17.1	51.9	0.0	968.2
Tanker orders (1000 CGT)	10,583	9.6	46.2	0.0	1119.0
Containership orders (1000 CGT)	4,813	18.9	93.9	0.0	1644.1
Observations With Positive Orders					
Bulk carrier orders (1000 CGT)	2,316	74.6	86.5	3.9	968.2
Tanker orders (1000 CGT)	1,436	70.4	107.1	0.05	1,119.0
Containership orders (1000 CGT)	625	145.3	222.7	2.3	1,644.1
Other Variables					
Bulk carrier backlog (1000 CGT)	10,101	171.4	329.3	0.0	2830.5
Tanker backlog (1000 CGT)	10,583	98.5	315.1	0.0	3840.8
Containership backlog (1000 CGT)	4,813	206.6	670.5	0.0	7362.8
Investment (mill RMB)	4,386	18.5	88.9	-240.5	1,770.7
Capital (mill RMB)	6,157	392.0	806.9	0.3	8,203.3

Note: Summary statistics for shipyards in China, Japan, and South Korea from 1998 Q1 to 2014 Q1. CGT is compensated gross tons, a widely used size measure and comparable across types. Bulk carriers, tankers, and containerships account for more than 90% of world orders in tons in our sample period. Investment and capital are limited to Chinese yards and measured in millions of 2000 RMB. Source: Clarksons and China's National Bureau of Statistics.

Table 2: Cost Function Estimates

	Bulk carrier		Tanker		Containership	
Type-specific	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
β_q	7.29	7.59	14.13	5.10	10.58	5.01
σ_ω	9.58	8.93	16.27	6.91	13.77	5.14
Constant (1000 RMB/CGT)	20.37	14.05	39.71	8.78	34.92	7.27
Steel Price (1000 RMB/Ton)	1.68	6.85	1.14	2.83	0.66	1.50
Capital (Bn RMB)	-2.67	-2.85	-2.89	-1.74	-2.44	-1.93
Capital^2	0.20	0.80	0.07	0.24	0.06	0.28
Backlog	-1.80	-5.03	-5.02	-4.97	-3.30	-3.19
Backlog^2	0.08	3.94	0.26	3.44	0.20	1.94
Backlog of Other Types	0.13	0.86	0.38	1.57	0.53	2.61
Common						
2006-2008	-2.10	-3.01				
2009+	-1.22	-1.78				
Large firms	-4.32	-6.54				
Jiangsu	-2.96	-4.61				
Zhejiang	-1.62	-2.80				
Liaoning	-2.10	-2.01				
CSSC/CSIC	-0.86	-1.17				
Private	0.16	0.30				
Foreign JV	-0.86	-1.41				
Age	0.21	3.22				
N	4886		4977		2504	

Note: Standard errors bootstrapped using 500 bootstrap samples. Marginal costs are measured in 1000 RMB per CGT. For example, a coefficient of -2.10 on the policy dummy ‘2006-2008’ implies that production subsidy during 2006-2008 is 2,100 RMB per CGT across ship types, or 14-18% of the average price.

Table 3: Estimates of Investment Cost and Scrap Value Parameters

	Coeff.	T-stat
σ_ϕ	0.98	12.32
$c_1 * 1\{2006-08\}$	-0.27	-1.70
$c_1 * 1\{2009+\}$	-0.46	-3.27
c_2	29.54	14.49
c_3	2.07	9.67
N	4286	

Note: Standard errors bootstrapped using 200 block bootstrap samples. Both investment and scrap value are measured in billions of 2000 constant RMB. Between 2006-2008, the subsidy was 0.27 RMB per RMB of investment. Post 2009, the subsidy jumps to 0.46 RMB per RMB of investment, which helps rationalize the elevated investment with plummeting ship prices post the financial crisis.

Table 4: Entry Cost Distribution (Mean) by Province in 2000 RMB (Bn)

	κ_{pre}	$\kappa_{post,06}$	% of pre costs	$\kappa_{post,09+}$	% of pre costs
Jiangsu	86	31	36%	91	106%
Zhejiang	133	54	41%	264	199%
Liaoning	82	40	49%	-	-
Other	38	15	38%	61	160%

Note: κ_{pre}: mean of the entry cost distribution prior to 2004 for Zhejiang, and prior to 2006 for Jiangsu, Liaoning and Other regions. $\kappa_{post,06}$: mean of the entry cost distribution between 2004 and 2008 for Zhejiang, between 2006 and 2008 for Jiangsu, Liaoning and Other regions. $\kappa_{post,09+}$: mean of the entry cost distribution from 2009 onwards. All entry costs are measured in billions of 2000 constant RMB. The number of potential entrants, $\bar{N}$, is assumed to equal twice the maximum number of potential entrants ever observed in a region. Compared to κ_{pre}, entry costs are much lower when entry subsidies were in place ($\kappa_{post,06}$) and much higher with entry restrictions ($\kappa_{post,09+}$). Conditional on entering, the average entry cost paid is RMB 2.5 billion, close to a shipyard's accounting value.

Table 5: Comparison of Policy Instruments

	All subsidies	Production subsidy	Investment subsidy	Entry subsidy	Remove all subsidies
Lifetime Revenue 2006-	2361	2154	1873	1961	1810
Lifetime Net Profit 2006-	1085	1061	981	1023	950
Production Subsidy	262	225	0	0	0
Investment Subsidy	77	0	42	0	0
Entry Subsidy	431	0	0	231	0
Δ Revenue/Subsidy	72%	153%	153%	66%	
Δ Net Profit/Subsidy	18%	50%	74%	32%	

Note: Revenue, net profit, and subsidy are discounted sums for Chinese shipyards from 2006 to 2050, averaged across simulations and measured in billions of 2000 constant RMB. For example, "Lifetime Revenue (Net Profit) 2006-" refers to the discounted sum of revenue (net profit) earned by Chinese firms from 2006 to 2050. "Net Profit": Revenue-Production Cost-Investment Cost+Scrap Value-Entry Cost. "ΔRevenue/Subsidy": the discounted sum of revenue in the column scenario minus the discounted sum of revenue with no subsidies, divided by the discounted sum of subsidies. "ΔNet Profit/Subsidy" equals the discounted sum of net profits in the column scenario minus the discounted sum of net profits with no subsidies, divided by the discounted sum of subsidies. Government policy in 2013 carries onward till the end of the simulation period (2050) in all columns. In Column "All subsidies", firms receive production and investment subsidy (as estimated in the baseline) in all periods, but entry subsidy terminates in 2009. In Column "Production subsidy", we maintain the same production subsidy as in the baseline, but shut down entry and investment subsidies. Columns "Investment subsidy" and "Entry subsidy" are similar.

Table 6: Pro-cyclical vs. Counter-cyclical Industrial Policy (in 2000 RMB, Bn

	Subsidize during boom	Subsidize during recession
Lifetime Revenue 2006-	1880	1872
Lifetime Profits 2006-	961	975
Production Subsidy	29	29
Investment Subsidy	13	14
Δ Revenue/Subsidy	189%	168%
Δ Net Profit/Subsidy	38%	70%

Note: In Column "Subsidize during boom," the government only subsidizes production and investment during the boom of 2006-08. In Column "Subsidize during recession," the government subsidizes during the recession of 2009-13, but offers no subsidy before 2009 or after 2013. The subsidy rates during the 2006-08 boom are adjusted downwards to match the amount handed out during the recession. No entry subsidy is offered in either scenario. All rows are defined as in Table 5. Monetary terms are deflated and measured in billions of 2000 constant RMB.

Table 7: Alternative Designs of Industrial Policy

	Permanent Subsidy	Temporary Subsidy 2006-2013	Targeted Temporary Subsidy 2006-2013	No subsidies
Lifetime Revenue 2006-	1708	1655	1614	1366
Lifetime Net Profit 2006-	969	991	1035	853
Production Subsidy	193	201	191	0
Investment Subsidy	55	49	54	0
Entry Subsidy	0	0	0	0
Total Subsidy	248	250	245	
Δ Revenue/Subsidy	138%	116%	101%	
Δ Net Profit/Subsidy	47%	55%	75%	

Note: This table reports the discounted sum of revenue, net profit, and subsidy from 2014 to 2050 in billions of 2000 constant RMB, averaged across simulations. Under the permanent subsidy, all firms receive production and investment subsidies from 2006 to 2050. Under the temporary subsidy, all firms receive production and investment subsidies from 2006 to 2013, after which subsidies are discontinued. Under targeted temporary subsidy, the 50 firms with the highest profitability at the beginning of 2006 receive subsidies from 2006 to 2013, after which subsidies are discontinued. Under the no-subsidy scenario, no firms receive any subsidies. Monetary terms are deflated and measured in billions of 2000 constant RMB.

Online Appendix for "China's Industrial Policy: an Empirical Evaluation"

Appendix A provides additional background on China's industrial policy and the data. Appendix B provides more details on the estimation procedure and identification. Appendix C presents additional estimation results. Appendix D describes how we implement the counterfactual analyses, as well as additional results. Finally, Appendix E examines the rationales of industrial policy.

A China's Industrial Policy and Data Description

A.1 Additional Background on Industrial Policies in China

Table A1 documents major national policies issued that were relevant for the shipbuilding sector. The most important initiative was the 11th National Five-Year Economic Plan (2006-2010) which dubbed shipbuilding as a strategic industry. The central government also issued a series of policy documents with specific production and capacity quotas. For example, as part of the 2006 *Medium and Long Term Development Plan of the Shipbuilding Industry*, the government set an annual production goal of 15 million deadweight tons (DWT) to be achieved by 2010, and 22 million DWT by 2015.

In the aftermath of the 2008 economic crisis that led to a sharp decline in global ship prices, the government promoted consolidation policies. The *Plan on Adjusting and Revitalizing the Shipbuilding Industry*, implemented in 2009, resulted in an immediate moratorium on entry with increased investment subsidies to existing firms. The most crucial policy for achieving consolidation objectives was the *Shipbuilding Industry Standard and Conditions* (2013), which instructed the government to periodically announce a list of selected firms that "meet the industry standard" and thus receive priority in subsidies and bank financing.[1] The so called "White List" included sixty firms in 2014 upon announcement.

The 12th Five-Year Plan for the Development of Shipbuilding Industry (2011-2015) set a number of targets for achieving increased industrial concentration, including 70% of the country's shipbuilding to be carried out by the top ten domestic firms, and at least five Chinese firms to be included in the world's top ten largest firms.

A.2 Data and Descriptive Patterns

This section describes how we measure firm entry, construct firm-level investment, and presents additional data patterns.

Entry, Investment, and Real Capital The entry year for a shipyard is defined as the first year it takes an order or the first year it delivers minus two years to account for the time it takes to build a

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[1] In practice, favorable financing terms and capital market access are often limited to firms on the White List post 2014.

Table A1: Shipbuilding National Industrial Policies

Year	Shipbuilding National Industrial Policies	Plan Period
2003	National Marine Economic Development Plan	2001-2010
2006	The 11th Five-Year Plan for National Economic and Social Development	2006-2010
2006	The Medium and Long Term Development Plan of Shipbuilding Industry	2006-2015
2007	The 11th Five-Year Plan for the Development of Shipbuilding Industry	2006-2010
2007	The 11th Five-Year Plan for the Development of Shipbuilding Technology	2006-2010
2007	11th Five-Year Plan for the Development of Ship Equipment Industry	2006-2010
2007	Guideline for Comprehensive Establishment of Modern Shipbuilding (2006-2010)	2006-2010
2007	Shipbuilding Operation Standards	2007-
2009	Plan on the Adjusting and Revitalizing the Shipbuilding Industry	2009-2011
2010	The 12th Five-Year Plan for National Economic and Social Development	2011-2015
2012	The 12th Five-Year Plan for the Development of the Shipbuilding Industry	2011-2015
2013	Plan on Accelerating Structural Adjustment and Promoting Transformation and Upgrading of the Shipbuilding Industry	2013-2015
2013	Shipbuilding Industry Standard and Conditions	2013-

ship, whichever is earlier. As an additional measure of firm entry, we extracted the registration information (date and business scope) for 90% of Chinese firms from the Trade and Industry Bureau database. The overall entry pattern is similar across these two measures: entry peaked in 2005-2007 and became minimal post 2009. We use the entry year from the Clarkson's database in our main analysis, as the registration data suffer from several limitations. First, it is difficult to identify firms whose core business is shipbuilding from the registration data alone, as firms often register with a wide business scope. In addition, some firms switch from ship repairs and marine equipment to shipbuilding years after their official registration.

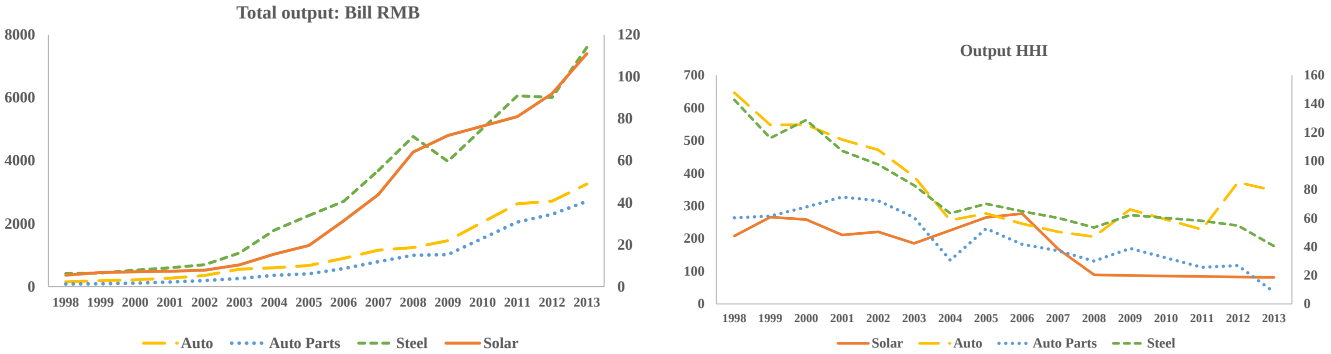
We calculate shipyard investment and real capital stock following the existing literature (Brandt et al., 2012), which is standard practice for papers that use the National Bureau of Statistics manufacturing survey. Specifically, firm investment is derived from variable 'F310' in the NBS survey, which is called "total fixed asset in original value". "Fixed asset" refers to buildings, structures, machinery, equipment, transportation vehicles and other equipment, apparatus, and tools that are related to production and operation, with a service life of more than one year. There is a related variable, F309, or "total fixed assets". We do not use F309 (except for pre-existing firms) because it includes both the original price of fixed assets and depreciation and firms might calculate depreciation in different ways.

The procedure for constructing real investment and real capital closely follows Brandt et al. (2012)): (i) Construct initial capital stock. If a firm is first seen after 1998, then we use their "total fixed assets in original value" (F310) from the first year we observe them in the NBS data. For firms first seen in 1998, we use their "total fixed asset" (F309). (ii) Measure nominal investment as the change in variable F310. (iii) Real investment = nominal investment deflated by NBS Price Index for "Fixed Assets Investment". (iv) Real Capital in period t = 97.7% * Real Capital in period t-1 + Real Investment in period t. Brandt et al. (2012) advocated this 2.3% quarterly depreciation to reflect China's high interest rates over our sample period.

Additional Data Patterns Figure A1 depicts China's total output and industry concentration in several industries. This illustrates that shipbuilding is not an outlier, but rather that in many other manufacturing industries during our sample period, industry growth was accompanied by low concentration.

China's shipbuilding industry ballooned after 2005 with the number of new shipyards setting historical records (Figure 1). Figure A2 illustrates that investment spiked from 2006 onwards for firms with different ownership structures, for firms in different provinces, as well as for both incumbents and new entrants. Similar patterns occur for production. These data patterns provide key identification variation in our estimation of government subsidies. In addition, Table A2 below reports the average price and quantity for each ship type before and after 2006.

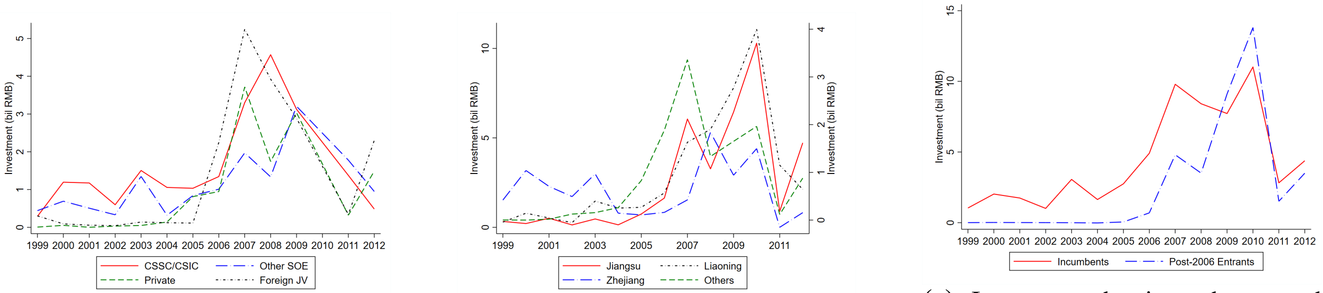
Figure A1: Output and Industry Concentration in Selected Chinese Industries



Source: China's National Bureau of Statistics. The output of the auto, auto parts, and steel industries are plotted on the left vertical axis, while the output of the solar industry is plotted on the right vertical axis.

Source: China's National Bureau of Statistics. The HHI of the auto and solar industries are plotted on the left vertical axis, while the HHI of the auto parts and steel industries are plotted on the right vertical axis.

Figure A2: Investment by ownership status, across provinces, by incumbents and entrants



(a) Investment by ownership status

(b) Investment across provinces

(c) Investment by incumbents and post-2006 entrants

Note: this figure plots aggregate investment in billions of 2000 constant RMB overtime. a) CSSC/CSIC refers to SOEs that are part of China State Shipbuilding Corporation (CSSC) and China Shipbuilding Industry Corporation (CSIC), while "Other SOEs" include all other SOEs. b) Investment in Jiangsu and other provinces is plotted on the left axis, while investment in Zhejiang (where firms tend to be smaller) and Liaoning (which has a smaller number of firms) is plotted on the right axis. c) Post-2006 entrants are firms that entered in 2006 or later.

Table A2: Average prices and quantity for different ship types, before and after 2006

	P, bulk	Q, bulk	P, tanker	Q, tanker	P, containerships	Q, containerships
Pre-2006	1.36	1.25	1.80	1.43	1.82	1.31
Post-2006	2.05	4.63	2.47	1.97	2.07	1.78

Note: Average prices are in 1000 USD/CGT. Average quantity is in million CGT.

B Estimation Details

B.1 Calibrating the Fixed Cost

The National Bureau of Statistics (NBS) data include information on operating costs, which allows us to calibrate the fixed cost of production. A firm's total production cost is equal to $C_{jt} = c_0 + C(q_{jt})$, where $C(q_{jt})$ is the estimated variable cost of taking q_{it} orders, as discussed in Section 4.1.

Some shipyards both produce ships and carry out repairs. We follow the standard assumption in the production literature that the cost share of ship production is the same as its revenue share and obtain the accounting operating cost of ship production as $\hat{C}_{jt} = C_{jt}^{NBS} * (R_j^{Clarkson}/R_j^{NBS})$, where C_{jt}^{NBS} denotes the accounting operating costs, which include the costs of both ship production and ship repairs. $R_j^{Clarkson} = \sum_t R_j^{Clarkson}$ denotes shipyard j's lifetime revenue from building new ships that is reported in Clarkson, and $R_j^{NBS} = \sum_t R_{jt}^{NBS}$ denotes its lifetime revenue in NBS.

We use two approaches to estimate the fixed cost c_0; both deliver similar results. The first approach uses the quarters with zero production (so that the variable production cost is zero) and the accounting costs $\hat{C}_{jt}$ (after adjusting for repairs) in the same periods to infer the fixed cost. The second approach uses the difference between a shipyard's average operating costs and the average estimated variable cost of production: $c_0 = \frac{1}{T}\sum_t[\hat{C}_{jt} - C(q_{jt})]$

B.2 Estimating the Investment Policy Function

Our analysis on investment abstracts away from divestment.[2] This is because compared to the massive investment undertaken by Chinese shipyards, divestment is much less common. The aggregate divestment is about 12% of the aggregate positive investment in the industry. Modeling the level of divestment introduces a kink in the cost function and makes the value function non-differentiable, which raises considerable computational challenges.

However, the baseline estimator of the first-stage investment policy function that is discussed in the paper (eqn. 12) does not formally account for the fact that investment is non-negative. Here, we perform two robustness checks. The first is a Tobit model that assumes $h_2(\nu_{jt})$ is normally distributed. The second approach assumes that the median of $h_2(\nu_{jt})$ is zero and estimates $h_1(s_{jt})$ using the Censored Least Absolute Deviation estimator (CLAD) that was first proposed by Powell (1984) and later extended

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[2] We treat divesting firms as having chosen zero investment in that period.

by Chernozhukov and Hong (2002). In this note, we describe how we implement the second approach based on the CLAD estimator.

The investment policy function is assumed to be additive in the observed state variables and the unobserved investment cost shock, with a non-negativity constraint:

$$I_{jt} = max(0, h_1(s_{jt}) + h_2(\nu_{jt}))$$

Powell (1984) showed that we can recover $h_1(s)$ through the Censored Least Absolute Deviations estimator (CLAD) while normalizing the median of $h_2(\nu_{jt})$ to 0. Once we obtain the CLAD estimate $\hat{h}_1(s_{jt})$, we treat $I_{jt} - \hat{h}_1(s_{jt})$ as data with the goal of estimating $h_2(\nu_{jt})$ with the truncated data:

$$\tilde{i}_{jt} \equiv I_{jt} - \hat{h}_1(s_{jt}) = max(h_2(\nu_{jt}), -\hat{h}_1(s_{jt})) = max(h_2(\nu_{jt}), \bar{h}_{jt})$$

where in the second equation we use $\bar{h}_{jt}$ to denote $-\hat{h}_1(s_{jt})$. Note that the level of truncation $\bar{h}_{jt}$ varies across observations. We use the observed probability of truncation (zero or negative investment) to back out the level of the investment shock that induces truncation, conditioning on the observed state variables (let Φ denote the CDF of a standard normal):

$$\begin{aligned} Pr(\tilde{i}_{jt} > \bar{h}_{jt}|\bar{h}_{jt}) = Pr(h_2(\nu_{jt}) > \bar{h}_{jt}) = Pr(\nu_{jt} < h_2^{-1}(\bar{h}_{jt})) = Pr(\nu_{jt} < \tilde{\nu}_{jt}) = \Phi(\bar{\nu}_{jt}), \text{or} \\ \bar{\nu}_{jt} = \Phi^{-1}\left(Pr(\tilde{i}_{jt} > \bar{h}_{jt}|\bar{h}_{jt})\right) \end{aligned}$$

where $Pr(\tilde{i}_{jt} > \bar{h}_{jt}|\bar{h}_{jt})$ can be estimated either via kernel methods, or by approximating the cutoff value $\bar{\nu}(\bar{h}_{jt})$ using a flexible function of $\bar{h}_{jt}$ and carrying out a probit regression.

To estimate $h_2(\nu_{jt})$, we categorize all the uncensored observations (where $\tilde{i}_{jt} > \bar{h}_{jt}$) into distinct bins. Suppose the thresholds are $\left\{\bar{h}_1, \bar{h}_2, ...\bar{h}_{R+1}\right\}$. Then any uncensored observation $\tilde{i} \in (\bar{h}_r, \bar{h}_{r+1}]$ is placed in bin r. We carry out the BBL inversion separately for each bin. If $i^* = max(h_2(\nu^*), \bar{h}_{jt})$ for some arbitrary ν^*, where i^* lies in bin r, then the following expression must hold:

$$\begin{aligned} F(i^*|i^* \in (\bar{h}_r, \bar{h}_{r+1}]) &= Pr(\tilde{i} \leq i^*|i^* \in (\bar{h}_r, \bar{h}_{r+1})) \\ &= Pr(\nu \geq \nu^*|\bar{\nu}_{r+1} < \nu < \bar{\nu}_r) \\ &= \frac{\Phi(\bar{\nu}_r) - \Phi(\nu^*)}{\Phi(\bar{\nu}_r) - \Phi(\bar{\nu}_{r+1})} \\ \text{Hence, } i^* &= F^{-1}\left(\frac{\Phi(\bar{\nu}_r) - \Phi(\nu^*)}{\Phi(\bar{\nu}_r) - \Phi(\bar{\nu}_{r+1})}\right) \text{ for } \bar{\nu}_{r+1} < \nu^* < \bar{\nu}_r \end{aligned}$$

It is easy to verify that this estimator nests the uncensored example as a special case and allows us to better address censoring by increasing the number of bins. Monte Carlo simulations suggest that a small number of bins (e.g. five) can lead to surprisingly well-behaved estimates with minimal bias in the estimated function $h_2(\nu)$.

As shown in Appendix Section C.2, Tobit and CLAD deliver similar estimates of the investment policy function as OLS, though OLS outperforms both Tobit and CLAD in terms of sample fitness.

B.3 Value Function Approximation

As discussed in the main text, we approximate the value function $V(s_{jt})$ via B-spline basis functions $V(s_{jt}) = \sum_{l=1}^{L} \gamma_l^0 u_l(s_{jt})$ and impose the Bellman equation as a constraint when estimating the dynamic parameters. This approach has several advantages. First, it avoids discretization and approximation errors therein when the state space is large. Second, replacing an unknown function with a finite set of unknown parameters substantially reduces the computational burden.Third, the accuracy of the value function approximation can be controlled via appropriate choices of basis functions and is directly benchmarked by the violation of the Bellman equation (13).[3] We now discuss how we approximate the value functions.

Constructing Basis Functions In our model, firm value functions are in principle a function of a large number of state variables. However, several state variables enter the shipyard's payoff as a single index $s_{jmt}\beta_{sm}$ in the marginal cost of production (equation 10), including the shipyard's region, ownership, size, age, and backlog. As such, instead of keeping track of each state separately, we collapse them into a single-dimensional state using the estimated coefficients:

$$\bar{s}_{jt} = -\sum_m s_{jmt}\beta_{sm}$$

We use $\bar{s}_{jt}$ as a measure of a firm's observed cost efficiency: a higher $\bar{s}_{jt}$ is associated with a lower marginal cost and a higher variable profit. Our approach of collapsing firm-level state variables into a single index is similar in spirit to Hendel and Nevo (2006) and Nevo and Rossi (2008) that use the "inclusive value" to capture the impact of changing product attributes on future profits. We further assume that $\bar{s}_{jt}$ evolves via a simple rule $\bar{s}_{jt+1} = \alpha_0 + \alpha_1 \bar{s}_{jt}$, which almost perfectly forecasts $\bar{s}_{jt+1}$ in period t since all but one of the variables in $\bar{s}_{jt}$ are deterministic.

Type-specific Cost Index The procedure above aggregates ship type-specific cost indices into one single index. One might be concerned that a firm that is efficient in producing one ship type but inefficient in other types will be treated the same as firms that are equally efficient in all types. But the type-specific cost indices are positively correlated (with a correlation of 0.585 between bulk and tanker, 0.530 between bulk and container and 0.304 between tanker and container), suggesting that firms that are better at producing one type are generally better at producing other types as well.

We carry out a robustness exercise where we include a separate cost index for each ship type m: $\bar{s}_{jmt} = -s_{jmt}\beta_{sm}, m \in \{\text{bulk,tanker,container}\}$ and repeat the estimation and counterfactual analyses.[4] Table B3 reports both the baseline specification with one cost index (first panel, labelled "Baseline"), as

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[3] We refer interested readers to supplemental material in Barwick and Pathak (2015) and Kalouptsidi (2018) for Monte Carlo evidence on the performance of value function approximations.

[4] It is difficult to separately identify the effect of type-specific cost indices $\{\bar{s}_{jmt}\}_m$ on policy functions. Thus, we restrict the coefficients for type-specific cost indices to be the same across ship types in the investment policy function and exit policy function. We also impose the restriction that the coefficients on interaction terms between $\bar{s}_{jmt}$ and aggregate ship and steel prices are the same across ship type m.

well as the estimated parameters with three cost indices (second panel, labeled "Type-specific"). The key parameters are robust in sign and magnitude. Results from the counterfactual analyses are also similar between these two specifications, where the predicted evolution of the industry closely mirrors each other, and the long-run welfare impacts of the subsidies are similar as well (the subsidy return was 18% in the baseline and 16% with type-specific cost indices). The similarity between the two specifications arises because firms that are better at producing one ship type in our sample are generally better at producing other ship types as well.[5]

Table B3: Estimates of Investment Cost and Scrap Value Parameters: Baseline vs. Robustness Check With Type-Specific Cost Index

	Baseline		Type-specific Cost Indices	
	Coeff.	T-stat	Coeff.	T-stat
Scrap value parameters				
σ_ϕ	0.98	12.32	0.71	7.34
Investment cost parameters				
$c_1 * 1\{2006-08\}$	-0.27	-1.70	-0.28	-1.64
$c_1 * 1\{2009+\}$	-0.46	-3.27	-0.40	-2.66
c_2	29.54	14.49	34.26	11.36
c_3	2.07	9.67	2.57	8.82

Note: Standard errors bootstrapped using 200 block bootstrap samples. Investment and investment cost are measured in billion RMB. The number of observations is 4286. σ_ϕ is the mean of the scrap value distribution. The investment cost is $C^i(i_{jt}, s_{jt}, \nu_{jt}) = c_1(s_{jt})i_{jt} + c_2 i_{jt}^2 + c_3 \nu_{jt} i_{jt}$, where c_1 is allowed to change during the policy periods 2006-08 and 2009+. In the baseline estimates, the state variables of a firm include a single-dimensional cost index $\bar{s}_{jt}$ (in addition to capital stock and exogenous state variables). In the specification labeled "Type-specific," the state of a firm includes a three-dimensional cost index $\{\bar{s}_{jmt}\}_m$, one for each ship type.

Estimating Value Function Approximation Coefficients The state variables (with one cost index) in the dynamic estimation are the capital stock, the price for each ship type, the steel price, and $\bar{s}_{jt}$ (which subsumes the remaining firm characteristics); as well as two policy dummies for the periods 2006-08 and post 2009. The basis functions are flexible third-order B-splines (i.e. quadratic piecewise polynomials). Given our focus on investment, we use two knots (and have experimented with more knots) in forming the B-splines for capital. The total number of basis functions is 44.

We search for $\{\gamma_l\}_{l=1}^L$ that minimize the violation of the Bellman equation (13) given the dynamic parameters:

$$\{\gamma_l\}_{l=1}^L = \arg\min_{\gamma_l} \left\| V(s_{jt};\gamma) - \pi(s_{jt}) - \hat{p}^x(s_{jt})\sigma_\phi - CV(s_{jt};\gamma) \right\|_2 \tag{B1}$$

where $\hat{p}^x(s_{jt})$ and $\hat{i}^*(s_{jt}, \nu_{jt})$ are the estimated first-stage exit and investment policy functions, respectively, $CV(s_{jt};\gamma) = \mathbb{E}_{\nu_{jt}}\left\{-C^i(\hat{i}^*(s_{jt}, \nu_{jt}), s_{jt}, \nu_{jt}) + \beta\mathbb{E}[V(s_{jt+1};\gamma)|s_{jt}, \hat{i}^*_{jt}]\right\}$ is the continuation value eval-

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[5] To further explore this, we have carried out regressions of short-run variable profits on the set of basis functions from our baseline, which consists of basis functions using the single cost index $\bar{s}_{jt}$ as well as other state variables. The R^2 is 0.94. Adding in basis functions based on type-specific cost indices increases the R^2 only marginally, from 0.94 to 0.98.

uated at these estimated policy functions, and $\|.\|_2$ is the L^2 norm. Equation (B1) is imposed as a constraint in the estimation of dynamic parameters. Specifically, for each guess of the dynamic parameters, we solve for $\{\gamma_l\}_{l=1}^{L}$ that satisfy equation (B1), and use the estimated $\{\hat{\gamma}_l\}_{l=1}^{L}$ to construct the sample log likelihood in equation (14).

Recovering the approximating coefficients γ requires specifying the set of state values on which to evaluate the Bellman constraint. We construct a sample that ensures sufficient variation in each of the state variables. First, we include all the N states observed in the sample. Second, we randomly draw N_{add} additional states to span the full range of the state variables. The coefficients γ are recovered using these $N+N_{add}$ states.[6] This approach is similar to Sweeting (2013). These additional states are instrumental in getting a good approximation of the value function, for two reasons. First, some states (for example, ship prices and the steel price) are highly correlated in the data, which makes it challenging to separately identify the coefficients on basis functions formed from these state variables if we only use the observed states. Second, some regions of the state space have a limited number of observations. Both of these problems can be mitigated by adding randomly drawn states, which avoids multicollinearity between states and ensures sufficient data points across all regions of the state space.

B.4 Identification

We next provide an intuitive discussion on the data variation that helps us identify the main structural parameters of our model. The key identification task in our empirical analysis is to recover the magnitude of government subsidies. Take entry subsidies and investment subsidies as an example. In our data, a massive entry wave of new Chinese shipyards occurred during the years when entry subsidies were in place (Figure 1). The number of entrants was modest for Japan (1.4 per year) and South Korea (1.2 per year). In contrast, the number of new shipyards in China registered a historic record and exceeded 30 per year when the entry subsidy was in place. Entry dropped to 15 in 2009 and became minimal within a couple of years of the implementation of the 2009 entry moratorium.

The rise in entry was accompanied by a large and unprecedented increase in capital expansion. The year of 2006 alone witnessed a steep four-fold increase in investment. The capital expansion was universal across both entrants and incumbents and among firms with different ownership status. For example, entrants account for 43% of the aggregate investment from 2006 to 2011, with the remaining 57% implemented by incumbents. Private firms, joint ventures, and SOEs account for 25%, 36%, and 38% of total investment, respectively. In addition, the capital expansion was spread out across all coastal provinces. Figure A2 illustrates that investment spiked from 2006 onwards for firms with different ownership structures, for firms in different provinces, as well as for both incumbents and new entrants. Similar patterns occur for production.

The drastic changes in firm entry, production, and investment aligned remarkably well with the policy timelines. In contrast, the economic fundamentals (or market forces) do not appear to fully rationalize

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[6] In our empirical analysis, $N=4,286$ and $N_{add}=80,000$. Using larger values of N_{add} leads to very similar estimates.

these data patterns. As Figure 1d shows, ship prices began rising around 2003, peaked in 2008, collapsed in the aftermath of the financial crisis, and remained stagnant from 2009 to 2013. China's production and investment, on the other hand, continued to expand well after the financial crisis. These patterns provide evidence that the Chinese government heavily subsidized this sector during our sample period.

Our estimates confirm this. Between 2006 to 2008, for each dollar of investment (not including the adjustment costs), the government subsidized 27 cents. After 2009, the investment subsidies increased to 46 cents of a dollar. This aligns with what we observe in the data and official documents quite well. Post 2009, the official documents indicate that the Chinese government shifted subsidies to existing firms (incumbents), expedited the capital appreciation clause, and set up dedicated banks to help shipyards raise funds. These policy shifts are consistent with our estimated higher investment subsidies post 2009. Similarly, we estimate that the production subsidy is 2,100 RMB per ton between 2006-2008, which is 14-18% of the average price, and 1,220 RMB per ton post 2009. It is worth noting that our estimates of the production subsidies match those in Kalouptsidi (2018), despite both papers having different estimation methods, sample periods, and industry coverage. Finally, the estimated entry subsidy varies from 51% of the entry cost in Liaoning to 64% in Jiangsu, which is needed to justify the entry waves in the data.

Our cost estimation shows that firms with larger capital stock, more backlog, the SOE ownership status, and located in the major shipbuilding regions in China (i.e., Jiangsu, Liaoning, and Zhejiang provinces) are more efficient in production. This reflects the data pattern that these firms produce more, given the market-level ship and steel prices. Our model interprets higher production as higher cost efficiency. In terms of the curvature of the marginal cost curve, if the cost of production is not too convex and increases modestly with the production level, then we should expect firms to expand production when ship prices increase. This is indeed what we observe in the data.

The investment costs are implicitly recovered through the observed investment. If firms invest a lot more during the subsidy years, it is likely driven by government subsidies once we have adequately controlled for higher ship prices and other state variables in the value function. The entry cost is recovered from the free entry condition and is roughly equal to the estimated discounted lifetime profit. One piece of evidence for the external validity is that our estimated entry cost is close to the accounting book value of shipyards. The scrap value is estimated from the observed exits in the data in an analogous manner.

C Additional Estimation Results

C.1 Demand Estimates

Table C4 reports estimates of the demand curve (9). Given the limited number of observations for each ship type, we restrict the price coefficient post-2006 and the coefficient on backlog to be the same across types in order to improve the precision of the estimates. We use GMM and estimate equation (9) jointly across the three types. Column (1) presents the simplest specification where the only demand shifter is the type-specific freight rate. Column (2) adds type-specific demand shifters. Column (3) further controls for a time trend, while Column (4) allows the time trend to differ before and after 2006. In all specifications, we allow for a different price coefficient before and after 2006 to capture changes in the slope of the demand curve after the introduction of Chinese subsidies. Adding demand shifters improves the fit, though time trends appear to matter little. As such we use Column (2) as our preferred specification.

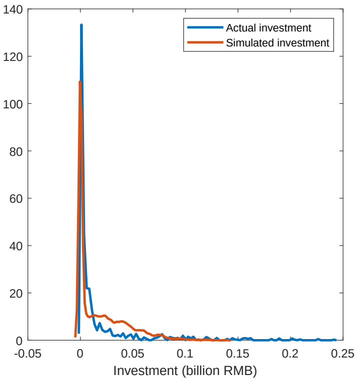
C.2 First-stage Policy Functions and State Transition Estimates

This section presents the first-stage estimates of investment and exit policy functions, as well as the state transition process. Table C5 reports the estimated investment policy function using OLS, Tobit, and CLAD. Table C6 reports the estimated exit policy function. Table C7 presents estimates of the transition process for the prices of bulk carriers, tankers, containerships, and steel.

C.3 Estimation of Dynamic Parameters: Model Fit

Table C8 compares the actual number of exits with model-predicted exits across 50 simulations. Firm exits are low-probability events and in general difficult to predict (Goldfarb and Xiao, 2016). Our model roughly matches the sample mean, though it under-predicts the number of exits post 2006. Table C9 compares the actual number of entrants with model-predicted number of entrants. Finally, Figure C3 plots both the distribution of actual investment as well as the distribution of model-predicted investment. These two distributions are reasonably similar, though actual investment has a long-tail of large investments and fewer medium-sized ones.

Figure C3: Simulated vs. Actual Investment



Note: For the model-predicted investment, we use the estimated parameters, randomly draw v for every observation, and plot the distribution of optimal investment predicted by the model.

Table C4: Demand Estimates

Dependent variable:	(1) Orders	(2) Orders	(3) Orders	(4) Orders
Demand coefficients that differ by ship type				
Bulk carriers				
Price (bulk carriers)	-2.34***	-1.67***	-2.07***	-2.12***
	(0.77)	(0.64)	(0.69)	(0.75)
Freight rate (bulk carriers)	2.84***	3.27***	3.35***	3.33***
	(0.45)	(0.56)	(0.57)	(0.56)
US Wheat price		-0.12	-0.10	-0.12
		(0.48)	(0.48)	(0.49)
Iron ore imports, China		2.62***	2.93***	3.01***
		(0.90)	(0.89)	(0.92)
Tankers				
Price (tankers)	-2.66***	-1.46*	-1.80**	-1.76**
	(0.60)	(0.88)	(0.78)	(0.89)
Freight rate (tankers)	4.04***	3.24***	2.94***	2.91***
	(0.70)	(0.68)	(0.65)	(0.65)
Middle East refinery production		1.37	1.84*	1.66*
		(1.05)	(0.97)	(0.99)
Containerships				
Price (containerships)	-4.85***	-2.44***	-3.39***	-3.39***
	(0.91)	(0.85)	(1.01)	(0.99)
Freight rate (containerships)	6.45***	4.47***	4.69***	4.60***
	(0.87)	(0.73)	(0.77)	(0.75)
World car trade		1.32***	2.08***	2.05***
		(0.44)	(0.49)	(0.49)
Coefficients restricted to be the same for all ship types				
Price*Post2006	1.34***	1.00***	1.15***	1.34**
	(0.18)	(0.14)	(0.15)	(0.55)
Backlog (log)	0.34	-1.00***	-0.78**	-0.81**
	(0.25)	(0.33)	(0.38)	(0.37)
Trend			-0.026**	-0.020
			(0.011)	(0.019)
Trend*Post2006				-0.0026
				(0.0076)
R^2, bulk carriers	0.68	0.71	0.71	0.71
R^2, tankers	0.26	0.33	0.35	0.36
R^2, containerships	0.44	0.52	0.51	0.51

Note: there are 64 observations for bulk carriers and containerships and 61 for tankers. The freight rate is the Baltic Exchange Freight Index for bulk carriers, Baltic Exchange Clean Tanker Index for tankers, and the Containership Timecharter Rate Index for containerships. The demand shifters include the US wheat price and total Chinese iron ore imports for bulk carriers, Middle East refinery production for tankers, and world car trade for containerships. We instrument ship prices using steel production and the steel ship plate price. Alternative cost-side instruments, such as the aggregate number of shipyards and the aggregate capital stock, lead to similar results. Parameters are estimated using GMM.

Table C5: Estimates Of The Investment Policy Function

	(1) OLS	(2) Tobit	(3) CLAD
Constant	-0.066	-12.2	-31.9***
	(7.54)	(8.17)	(4.09)
B-spline 1 Capital	-69.7***	-63.8***	-69.6***
	(22.0)	(17.2)	(1.67)
B-spline 2 Capital	-74.7***	-71.7***	-68.2***
	(17.7)	(13.5)	(1.41)
2006-08	6.42***	4.59**	17.9***
	(1.60)	(2.32)	(0.74)
2009+	2.70	3.79	3.55**
	(2.20)	(3.03)	(1.80)
$\bar{s}_{jt}$	0.74***	0.87***	1.44***
	(0.11)	(0.087)	(0.040)
Bulk carrier price	2.05***	1.97***	1.34***
	(0.46)	(0.57)	(0.30)
Tanker price	0.48	1.89*	0.81***
	(0.93)	(1.14)	(0.13)
Containership price	-1.25	-1.49	-0.55
	(0.87)	(1.06)	(0.34)
Steel price	-2.49***	-4.44***	-4.38***
	(0.53)	(0.61)	(0.19)
N	4286		
$N(I>0)$	3301		
$N(I=0)$	985		

Note: In column (1), we carry out an OLS regression of investment (I) on basis functions of state variables, including both observations with $I > 0$ and $I = 0$. In column (2), we estimate the policy function using a Tobit regression. In column (3), we estimate the investment policy function using a censored least absolute deviations estimator. $\bar{s}_{jt}$ is a production-efficiency index that captures the effect of backlog, age, ownership, region, and size on a firm's per-period payoffs. Investment is measured in millions of 2000 constant RMB.

Table C6: Estimates of the Exit Policy Function

	(1)		(2)	
	Coefficient	SE	Coefficient	SE
Constant	-0.57	(0.97)	-0.56	(1.02)
K	0.05	(0.35)	0.54	(0.43)
K^2	-0.05	(0.12)	-0.16	(0.15)
2006-2008	-0.57	(0.41)	-0.64	(0.43)
2009+	-0.47	(0.41)	-0.72	(0.44)
$\bar{s}_{jt}$	-0.01	(0.01)	-0.04	(0.02)
Bulk carrier price	0.36	(0.12)	0.36	(0.12)
Tanker price	-0.18	(0.11)	-0.16	(0.11)
Containership price	-0.22	(0.10)	-0.25	(0.11)
Steel price	-0.06	(0.07)	-0.10	(0.08)
Jiangsu			0.77	(0.24)
Zhejiang			0.58	(0.19)
Liaoning			1.04	(0.28)
N	4605		4605	
Log-likelihood	-239.30		-229.74	
Pseudo-R2	0.09		0.12	

Note: We carry out a probit regression of a binary indicator of exit on basis functions of state variables. We restrict the estimation to 1999-2011, because firm exits in 2012 and 2013 are not reliably measured as our sample of orders ends in Q1 2014.

Table C7: AR(1) Estimates for State Transition Processes

	Bulk carriers	Tankers	Containerships	Steel
Constant	0.88	0.70	1.25	-0.023
	(0.87)	(0.94)	(1.11)	(0.37)
Post	3.44	3.63	1.80	2.32
	(2.28)	(3.43)	(3.33)	(1.01)
Price (t-1)*Pre	0.86	0.92	0.88	0.89
	(0.12)	(0.086)	(0.090)	(0.19)
Price (t-1)*Post	0.86	0.86	0.88	0.69
	(0.072)	(0.095)	(0.10)	(0.11)
Trend*Pre	0.042	0.038	0.029	0.024
	(0.033)	(0.028)	(0.024)	(0.027)
Trend*Post	-0.058	-0.054	-0.040	-0.022
	(0.027)	(0.041)	(0.040)	(0.013)
N	57	57	57	57
R^2	0.95	0.97	0.96	0.80

Note: The dependent variable is the price in quarter t. Standard errors in parenthesis. “Pre” refers to 2005Q4 or earlier. “Post” refers to 2006Q1 or later. The sample ranges from 1999 Q4 to 2013Q4.

Table C8: Actual vs. Simulated Exit

	1999-2005	2006-2013	Total
Actual exits	5	43	48
Simulated exits	9	32	41

Note: We simulate the model 50 times from 1999 to 2013 and report the average number of exits.

Table C9: Actual vs. Simulated Entrants

	Pre	Post, Until 2008	Post, 2009+	Total
Actual entries	83	122	39	244
Simulated entries	65	132	28	225

Note: "Pre"refers to the period prior to 2004 for Zhejiang, and prior to 2006 for all other regions. "Post, Until 2008" refers to the period between 2004 and 2008 for Zhejiang and between 2006 and 2008 for all other regions. "Post, 2009+" refers to the period from 2009 onwards. We simulate the model 50 times from 1999 to 2013 under the baseline and report the average number of entries across these simulations.

C.4 Production Cost Estimates: Robustness

This section carries out several robustness analyses for production cost estimates. First, we estimate production costs assuming the firms are price-takers rather than Cournot competitors. Table C10 shows that the estimated coefficients remain quantitatively similar. We then explore how our estimates of ship production costs change when we pool data from China, Japan and South Korea. As the capital stock is unobserved for firms in Japan and South Korea, we set these shipyards' capital to zero and add country dummies. The results are illustrated in the first panel of Table C11. The key coefficients are generally similar to those in the baseline. The subsidy is estimated to be higher in the 2006-08 period but somewhat lower in the 2009+ period.

Next, we examine evidence of learning-by-doing by shipyards. First, we evaluate within-firm learning-by-doing by allowing a firm's marginal cost to depend on its cumulative past production. As shown in the second panel of Table C11, a larger past production leads to higher marginal costs, which is inconsistent with there being within-firm learning-by-doing. Second, we allow a firm's marginal cost to depend on the industry cumulative output, as a crude test of industry-wide learning-by-doing (where firms learn from each other). We find limited evidence for spillover effects (the third panel of Table C11). Marginal costs increase with the cumulative industry production for tankers and containerships. They decrease modestly for bulk carriers, but the coefficient is statistically insignificant and small in magnitude.

Table C12 reports results from additional robustness exercises. First, we allow for a time trend in the cost function. This captures changes in the production technology over time. The time trend is estimated to be very small in magnitude and has little effect on other estimated cost parameters. Second, we repeat the analysis on a sub-sample that excludes Chinese yards that entered after the policies were announced (which might have newer technology). The results are robust and broadly similar to other specifications.

Table C10: Cost Function Estimates under Perfect Competition vs. Cournot Competition

	Bulk carrier		Tanker		Containership	
	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
Cournot						
Capital (bn RMB)	-2.67	-2.85	-2.89	-1.74	-2.44	-1.93
Backlog	-1.80	-5.03	-5.02	-4.97	-3.30	-3.19
2006-2008	-2.10	-3.01				
2009+	-1.22	-1.78				
Perfect competition						
Capital (bn RMB)	-2.43	-2.96	-2.61	-1.80	-2.19	-2.01
Backlog	-1.56	-5.29	-4.44	-5.04	-2.88	-3.34
2006-2008	-1.51	-2.62				
2009+	-1.38	-2.37				
N	4886		4977		2504	

Note: The first panel reports the baseline cost function estimates from Table 2, which assumes that firms compete in Cournot. The second panel reports the cost estimates assuming perfect competition. The table reports estimates for key coefficients. Full tables are available upon request. Marginal costs measured in 1000 RMB per CGT. Standard errors bootstrapped using 500 bootstrap samples.

Table C11: Cost Function Estimates and Learning: Shipyards in All Three Countries

	Bulk carrier		Tanker		Containership	
Type-specific	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
Baseline specification (all countries)						
Capital (bn RMB)	-3.33	-2.98	-2.47	-1.53	-1.57	-1.28
Backlog	-2.45	-6.14	-5.45	-6.05	-3.58	-4.27
Allow for within-firm learning						
Capital (bn RMB)	-2.16	-1.85	-2.29	-1.43	-1.22	-1.12
Backlog	-1.67	-4.78	-5.30	-5.09	-1.13	-1.40
Cumulative Q	0.08	4.12	0.10	5.22	0.02	3.60
Allow for within-firm and industry-wide learning						
Capital (bn RMB)	-2.48	-2.14	-4.80	-1.66	-2.81	-1.26
Backlog	-1.60	-4.14	-9.24	-3.67	-2.47	-1.15
Cumulative Q	0.09	4.49	0.18	3.93	0.03	2.58
Cumulative Q, China	-0.02	-0.79	0.39	2.10	0.68	1.61
N	10013		10429		4661	

Note: All panels pool together Chinese/Japanese/Korean yards. The second panel includes all regressors from the first panel, as well as each firm's cumulative past production. The third panel includes all regressors from the first panel, each firm's cumulative past production, and the country's cumulative past production. The table reports backlog coefficient for Chinese shipyards; backlog coefficients for Japan and Korea are not reported to save space. Full tables are available upon request. Standard errors bootstrapped using 500 bootstrap samples.

Table C12: Cost Function Estimates: Additional Robustness Checks

	Bulk carrier		Tanker		Containership	
	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
Baseline specification (all countries)						
Capital (bn RMB)	-3.33	-2.98	-2.47	-1.53	-1.57	-1.28
Backlog	-2.45	-6.14	-5.45	-6.05	-3.58	-4.27
China 2006-2008	-3.60	-4.85				
China 2009+	-0.70	-1.02				
Add time trend						
Capital (bn RMB)	-3.40	-2.93	-2.51	-1.57	-1.60	-1.23
Backlog	-2.49	-6.06	-5.51	-5.90	-3.64	-3.99
China 2006-2008	-3.76	-4.48				
China 2009+	-0.87	-1.19				
Trend	0.03	0.50				
Existing yards						
Capital (bn RMB)	-3.98	-3.04	-3.26	-1.39	-0.48	-0.35
Backlog	-3.90	-5.71	-6.73	-5.77	-4.38	-3.94
China 2006-2008	-3.01	-3.03				
China 2009+	-0.92	-0.91				
N	10013		10429		4661	

Note: this table reports additional robustness pooling shipyards from all three countries. The second panel includes all regressors from the first panel, as well as a quarterly time trend. The third panel repeats the regression from the first panel on a sub-sample of shipyards and excludes Chinese yards that entered after the policies were announced. The table reports backlog coefficients only for Chinese shipyards. Full tables are available upon request. Standard errors bootstrapped using 500 bootstrap samples.

C.5 Production Cost Estimates: Price Endogeneity

The production cost analysis in Section 4.1 in the main text and Section C.4 assumes that the marginal cost shock ω_{jmt} is independent of the ship price P_{mt}. This assumption is violated if favorable cost shocks ω_{jmt} lead to higher aggregate industry production, which then affects ship prices. In the analyses below, we allow ω_{jmt} to be correlated with the ship price P_{mt}. That is, we allow the ship price to be endogenous. To address this issue, we use ship demand shifters as IVs and adopt a control function approach following the econometric literature (MacKinnon and Olewiler, 1980; Smith and Blundell, 1986; Newey, 1987; Chernozhukov et al., 2015).

Methodology: We begin by estimating a reduced-form equation for equilibrium prices that includes demand shifters d_{mt} (e.g., freight rates, wheat price, etc.) as well as cost shifters x_{mt} (e.g., steel price, subsidy dummies), as in the papers mentioned above:

$$P_{mt} = \bar{\alpha}_{0m} + d'_{mt}\bar{\alpha}_{dm} + x'_{mt}\bar{\alpha}_{xm} + \eta^{d}_{mt} \tag{C2}$$

Note that all variables in x_{mt} are included in s_{jmt}. That is, they directly affect the marginal costs of firms. The demand shifters d_{mt} are assumed to be uncorrelated with firm-level cost shocks ω_{jmt}. This is the key *identifying* assumption that allows us to utilize d_{mt} as excluded instruments for P_{mt}. The other controls x_{mt} are included in the marginal cost equation and uncorrelated with ω_{jmt}. Thus, the only additional assumption we are making is that d_{mt} and ω_{jmt} are uncorrelated. We maintain the assumption that η^d_{mt} is normally distributed because it allows us to continue using a likelihood-based Tobit estimator. In principle, it is possible to relax this assumption and utilize a semi-parametric estimator, as in Blundell and Powell (2007) and Chernozhukov et al. (2015).

Let the variances of η^d_{mt} and ω_{jmt} be denoted by σ^2_η and σ^2_ω respectively, while ρ denotes the correlation between η^d_{mt} and ω_{jmt}. Because η^d_{mt} and ω_{jmt} are both normally distributed, we can write ω_{jmt} as a function of η^d_{mt} (MacKinnon and Olewiler, 1980):

$$\omega_{jmt} = \rho(\sigma_\omega/\sigma_\eta)\eta^d_{mt} + e_{jmt} \tag{C3}$$

where e_{jmt} is also normally distributed with variance $(1-\rho^2)\sigma^2_\omega$. Crucially, it is independent of η^d_{mt}. Plug Equation (C3) into Equation (10) for q_{jmt}:

$$q^*_{jmt} = \bar{\beta}_{qm}(P_{mt} - \beta_{0m} - s_{jmt}\beta_{sm} - \rho(\sigma_\omega/\sigma_\eta)\eta^d_{mt} - e_{jmt}) \tag{C4}$$

$$q_{jmt} = max\{0, q^*_{jmt}\} \tag{C5}$$

The above system of equations can now be estimated using MLE, since e_{jmt} is uncorrelated with all other regressors (including P_{mt} and η^d_{mt}) by construction, and η_{mt} is replaced with the residual $\hat{\eta}_{mt}$ from price equation (C2).[7]

It should be noted that without censoring, the control function approach yields identical results to the usual instrumental variable estimation (where we use demand shifters as instruments for P_{mt} when estimating the supply side). It is censoring in our setting (quantities are non-negative) that necessitates the use of the control function approach.

Implementation and Results: We use the following demand shifters as excluded instruments for price for each ship type: (1) bulk freight rates, US wheat price, and iron ore imports for bulk; (2) tanker freight rates and Middle East refinery production for tankers; and (3) container freight rates and world car trade for containerships. These demand shifters are unlikely to be correlated with firm-level ship production cost shocks and thus may be considered valid instruments. The cost shifters x_{mt} include steel prices and steel production, as well as subsidy dummies (2006 - 2008, 2009 - 2013), which are controls in the quantity equation (10).

Table C13 presents the cost function estimates using the control function approach. For comparison, we also include the baseline estimates where we do not deal with endogeneity. The coefficient estimates are very similar to our baseline estimates. Moreover, the estimate of ρ, which is the correlation between ω_{jmt} and η_{mt}, is small in magnitude (which varies from 0.005 to 0.03 in absolute value across ship

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[7] Smith and Blundell (1986) shows that replacing η_{mt} with the residual $\hat{\eta}_{mt}$ still leads to consistent estimates.

types), suggesting that there is limited endogeneity bias in our setting. Our estimates are robust to the set of controls in the reduced-form pricing regression, such as controlling for type-specific aggregate industry backlog or aggregate time trend. The estimated correlation coefficient ρ is small in magnitude in every case, varying between 0.002 and 0.05 in absolute value. These patterns are perhaps expected, as our specification for firms' marginal cost includes a rich set of aggregate controls that leaves little room for the correlation between aggregate ship prices and firm-level cost shocks.

Table C13: Production Cost Estimates Using the Control Function Approach

	Bulk Carrier		Tanker		Containership	
	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
Baseline (no instruments)						
Capital (bn RMB)	-2.67	-2.85	-2.89	-1.74	-2.44	-1.93
Backlog	-1.80	-5.03	-5.02	-4.97	-3.30	-3.19
2006-2008	-2.10	-3.01				
2009+	-1.22	-1.78				
Control function approach						
Capital (bn RMB)	-2.58	-2.75	-2.89	-1.74	-2.34	-1.90
Backlog	-1.72	-4.91	-4.94	-4.47	-3.21	-3.09
ρ	0.01	0.62	-0.005	-0.159	0.03	1.15
2006-2008	-1.98	-2.66				
2009+	-1.28	-1.93				
N	4886		4977		2504	

Note: The first panel reports baseline estimates, while the second panel shows estimates from using the control function approach. When implementing the control function approach, we include the following type-specific controls in the reduced-form price equation (C2): (i) for bulkers, we include the bulk freight rate, China iron ore imports, and wheat price; (ii) for tankers, we include Middle East refinery production and tanker freight rate; (iii) for containerships, we include container freight rate and world car trade. For all ship types, we include dummies for China's policy intervention periods (2006 - 2008, 2009+), steel price, and steel production, which are controls for firms' production cost shifters. The table reports key coefficients to conserve space. Full tables are available upon request.

D Counterfactual Exercises: Details

D.1 Implementation of Counterfactual Analyses

Each counterfactual analysis involves two steps: first, solving for the new Bellman equation and policy functions, and second, simulating the industry forward until 2050. Here we briefly explain how to implement the first step through a fixed point algorithm:

1. Compute expected profits $\pi(s)$ at all states.
2. Start with an initial guess of the exit policy function $p^{0,x}(s)$ and investment policy function $i^0(s,\nu)$.

3. Update the policy functions. At each iteration j:

    - Solve for the value function coefficients γ^{j+1} using: $V^{j+1}(s) = \pi(s) + p^{j,x}\sigma + CV^{j+1}(s)$.
    - Update the investment policy function to $i^{j+1}(s, \nu)$ by solving the investment FOC, using V^{j+1} and CV^{j+1}. As the value function is approximated by cubic B-splines, the investment policy function has an analytic solution.
    - Update the exit policy function to $p^{j+1,x}$ using V^{j+1} and CV^{j+1}.
    - Check whether $||p^{j+1,x}(s) - p^{j,x}(s)|| < tol$ and $||i^{j+1}(s,\nu) - i^{j}(s,\nu)|| < tol$, where tol is a pre-assigned tolerance level.

D.2 Methodology for Counterfactual Analyses with Temporary Subsidies

In the majority of our analysis we have assumed that government policies are perceived as permanent by all firms, similar to other dynamic papers that feature firm entry, exit, and investment (e.g., Ryan (2012)). This implies that the equilibrium before and after the policy is stationary, and we can employ standard contraction mapping arguments to solve for firm value functions. In order to analyze industrial policies that are explicitly temporary in nature (where the subsidies last until period T) and make firms' value functions *non-stationary*, we employ non-stationary dynamic programming techniques to compute firms' value functions. We take advantage of the fact that once the subsidies expire in period T, the industry enters into a stationary equilibrium where there is no further change in policies. Thus, we can use the dynamic programming techniques described above to solve for the value function from period T onwards. We then use backward induction to solve for the value function in all periods before period T when the subsidies are in place.

To fix the notation, let V with no superscript represent the ex-ante value function once the industry reaches period T and the subsidies are phased out permanently. Let V^r denote the ex-ante value function in period r with $r < T$. Similarly, let CV represent the continuation value in period T or after, and CV^r represent the continuation value in any period before T. We describe below how we perform the backward induction for the period $T-1$ (the period immediately preceding the phasing-out). The procedure for earlier periods $r < T-1$ is identical.

The ex-ante value function in period $T-1$ can be written as:

$$V^{T-1}(s_{j,T-1}) = \pi(s_{j,T-1}) + p^{x}_{T-1}(s_{j,T-1})\sigma_{\phi} + CV^{T-1}(s_{j,T-1}) \tag{D6}$$

where

$$CV^{T-1}(s_{j,T-1}) = E_{\nu_{j,T-1}}\Big(-C^{i}(i^{*}_{T-1}, s_{j,T-1}, \nu_{j,T-1}) + \beta E[V(s_{j,T}|s_{j,T-1}, i^{*}_{T-1})\Big) \tag{D7}$$

To solve for V^{T-1} via backward induction, take the following steps: (1) First, solve for i^{*}_{T-1}, the optimal investment policy function in period $T-1$ that maximizes the firm's value (conditional on observing the investment shock $\nu_{j,T-1}$), which equals $\big(-C^{i}(i^{*}_{T-1}, s_{j,T-1}, \nu_{j,T-1}) + \beta E[V(s_{j,T}|s_{j,T-1}, i^{*}_{T-1})\big)$.

(2) Use equation (D7) to solve for CV^{T-1}, integrating over investment cost shocks $\nu_{j,T-1}$.

(3) Next, solve for $p^x_{T-1}(s_{j,T-1})$, the new exit policy function in period $T-1$:

$$p^x_{T-1}(s_{j,T-1}) \equiv \Pr\left(\phi_{jt} > CV^{T-1}(s_{j,T-1})\right) = 1 - F_\phi\left(CV^{T-1}(s_{j,T-1})\right) \tag{D8}$$

(4) Finally, solve for V^{T-1} using equation (D6). Similar to how we approximate V (the stationary value function after the subsidies are removed), we also approximate V^{T-1} via B-spline basis functions of the state variables. We assume that $V^{T-1}(s_{j,T-1}) = \sum_{l=1}^{L} \gamma_l^{T-1} u_l(s_{j,T-1})$. We search for the unknown approximation parameters γ_l^{T-1} that minimize the violation of the Bellman equation (D6).

D.3 Additional Counterfactual Results

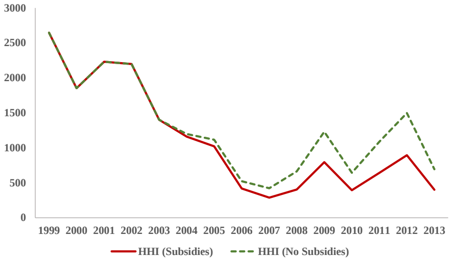
This subsection presents additional details on counterfactual analyses in Section 6 of the main text.

Effects on Ship Price and HHI: Table D14 shows the effect of subsidies on ship prices. We show average prices for different ship types (bulk carriers, tankers and containerships), both for the 2006-08 period and the 2009-13 period. Figure D4 shows the HHI of the Chinese shipbuilding industry, both in the baseline scenario as well as in a scenario where firms do not receive any subsidies.

Table D14: Impact of Subsidies on Ship Prices (in 1000 RMB/CGT)

	Bulk	Tanker	Container
Subsidies, 2006-08	16.4	20.7	17.4
No subsidies, 2006-08	18.1	22.8	18.2
% difference	9.9%	10.1%	4.3%
Subsidies, 2009-13	8.8	6.4	9.0
No Subsidies, 2009-13	10.2	7.3	9.4
% difference	16.8%	14.8%	4.2%

Figure D4: HHI For Chinese Shipbuilding, with and without Subsidies



Notes: The HHI reported in the above figure is calculated using all Chinese yards in a given year. It measures the concentration of the Chinese shipbuilding industry.

Comparison between Production, Investment, and Entry Subsidy Table D15 presents the results from a counterfactual simulation comparing production and investment subsidies. The first column considers a scenario where firms receive only production subsidies at the baseline rate. In the third column, firms receive only investment subsidies. Investment subsidies appear less distortionary than production subsidies (74% vs. 50%).

However, this comparison is confounded by the larger magnitude of the production subsidies, as bigger subsidies are associated with more distortion. In the second column, we reduce the per-unit production subsidies by 75% to make the total amount of these two subsidies comparable. The return to investment subsidies remains higher, though the difference is smaller (74% vs 62%). Investment subsidies lead to a higher level of capital formation over the long run, which facilitates long-term industry growth, while production subsidies have a more immediate impact on output. Production subsidies are slightly more effective at increasing revenue: the increase in revenue per RMB of subsidy is 1.9 RMB for production subsidies, versus 1.5 RMB for investment subsidies.

Table D15: Comparing Production and Investment Subsidies in 2000 RMB (Bn)

	100% Production Subsidy	25% Production Subsidy	Investment Subsidy
Lifetime Revenue 2006-	2154	1898	1873
Lifetime Net Profit 2006-	1061	978	981
Production Subsidy	225	47	0
Investment Subsidy	0	0	42
Δ Revenue /Subsidy	153%	190%	153%
Δ Net Profit/Subsidy	50%	62%	74%

Note: Revenue, net profit, and subsidy are the discounted sum from 2006 to 2050 in billions of 2000 constant RMB and averaged across simulations. ΔRevenue/Subsidy and ΔNet Profit/Subsidy are defined as in Table 5. In scenario "100% Production Subsidy", we keep the production subsidy at the baseline estimate, but shut down entry and investment subsidies. In scenario "25% Production Subsidy", we set the per unit production subsidy to 25% of the baseline estimate to make the aggregate subsidy amount in the last two columns similar. In scenario "Investment Subsidy", we keep investment subsidy but shut down entry and production subsidies. In all scenarios, the 2013 government policy carries onward till the end of the simulation period (2050).

Table D16: Take-up of Subsidies by Productive and Unproductive Firms

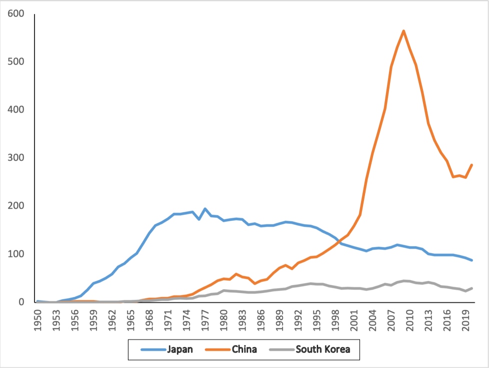
	Less productive firms	More productive firms
Lifetime Revenue 2006-	439	1923
Lifetime Profit 2006-	198	887
Production Subsidy	45	217
Investment Subsidy	24	53
Entry Subsidy	218	213

Note: We use the median $\bar{s}_{jt}$ among firms active in 2006 as a cutoff to define productive firms. "Less productive" firms are firms whose initial $\bar{s}_{jt}$ is below this cutoff, while "more productive" firms have initial $\bar{s}_{jt}$ above the cutoff.

In contrast to production and investment subsidies that are more likely to go to efficient firms, inefficient and efficient entrants are equally likely to take up entry subsidies. As shown in Table D16, 82% of production subsidies and 68% of investment subsidies are allocated to firms that are more efficient than the median firm (as measured by $\bar{s}_{jt}$), whereas only 49% of entry subsidies go to more efficient firms.

Finally, the conclusion that entry subsidies are wasteful is driven by observed data patterns. The estimates reported in Table 2 suggest that entrants, which are small in scale, are less efficient in production. Compared to firms that existed prior to the entry subsidies, new entrants are more likely to be idle (74% vs 56%) and less likely to make investments (61% vs 72%). Using additional data that spans until 2022, we find that many of the newly entered shipyards exited the market after the financial crisis. The number of active shipyards in China has declined by almost 50% from its peak in 2009 to 2020 (Figure D5).

Figure D5: Number of Active Shipyards



Boom and Bust One may be concerned that our counterfactuals are affected by the observed boom and bust that coincided with the subsidies. This is because the performance of different policies could depend on the specific demand movements that occurred. To address this concern, we perform a series of counterfactuals where we shut down the aggregate demand shocks and evaluate the policy effectiveness at the steady-state aggregate demand. Table D17 shows that the return on subsidies is slightly higher in these steady-state counterfactuals (23%) compared to our baseline counterfactuals where demand goes through a boom and bust cycle (where the return was 18%). The reason business cycles have a moderate effect is that when we calculate the policy return using the differences between the subsidy scenario and the no-subsidy scenario, we control for the business cycles (such as the boom and bust in our sample) and aggregate demand shifters in both scenarios. The booms and busts only modestly exacerbate the low return of industrial policies due to the convexity of production and investment costs.

Financial Burden of Subsidies Our analyses assume that all subsidies are financial (involving monetary resources). However, some “subsidies” or policy interventions might not be financial. Our understanding of the government policies is that production and investment subsidies are likely to be financial (monetary in nature), such as government-sponsored buyer financing, export credits in the form of value-added-tax refunds, and low-interest loans. The entry subsidies are a bit more complicated. Some entry subsidies consist of subsidized land, which is also monetary. On the other hand, simplifying the entry procedure to make it easier for firms to enter might not directly involve financial resources. To overcome this challenge, we take advantage of a 2014 large-scale entry-registration reform that drastically

Table D17: Return on Industrial Policy: Steady-state vs. Observed Demand

	Subsidies		No Subsidies	
	Baseline	Steady-state	Baseline	Steady-state
Lifetime Revenue 2006-	2361	1826	1810	1366
Lifetime Profits 2006-	1085	996	950	853
Production subsidies	262	216	0	0
Investment subsidies	77	70	0	0
Entry subsidies	431	342	0	0
Δ Revenue/Subsidy	72%	73%		
Δ Net Profit/Subsidy	18%	23%		

Note: This table reports the discounted sum of revenue, net profit, and subsidy from 2014 to 2050 in billions of 2000 constant RMB, averaged across simulations. Under the steady-state versions of the counter-factuals, we shut down any aggregate demand shocks and assume that demand is always at its steady-state level.

simplified the registration process (which turned the multi-year, multi-agency registration process into a 'one-stop' process that can be done electronically and within a few days in many cases). As a result of this reform, China's ranking in terms of the relative ease of starting businesses compiled by the World Bank improved from *150th* among 183 regions and countries in 2011 to *27th* in 2020.

Barwick et al. (2022) found that this entry-registration reform increased the entry rate by 25% for manufacturing industries. Firm-level entry in our sample increased by 220% between 2006 - 2008, the period when entry was directly subsidized. This increase in entry rates is significantly higher than the 25% effect size of the entry reform. If we were to take into consideration the effect of simplified registration procedures and assume that streamlining the entry process is costless, then the actual entry subsidies in dollar terms would be approximately 30% lower than our current estimates.[8] Incorporating this consideration only increases slightly the return on China's industrial policy in our sample period from 18% to 21%.

Actual vs. Optimal White List Policies Table D18 shows the differential policy impact if the government were to only subsidize White List firms (2nd column), as opposed to subsidizing all firms in the industry after 2013 (1st column). We include the top 56 firms with highest profitability to form the White List. As a benchmark we also show industry revenues and profits if the government were to discontinue subsidies entirely after 2013. This analysis assumes that the government chooses the White List optimally. We have examined the performance of firms on the actual White List and those on the optimal White List (2nd column of Table D18). To ease comparison, all other firms were forced to exit in 2013 and subsidies discontinued post 2013. The difference in the long-term industry profits and revenue (the discounted sum from 2014 to 2050) between the optimal and the actual White List is 12% and 8%, respectively.

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[8] We calculate this by estimating the magnitude of entry subsidies that would generate a 25% increase in the number of new firms. We find that this requires an entry subsidy that is equal to 30% of the currently estimated entry subsidies.

Table D18: Targeting Subsidies to White List Firms (in Bn RMB)

	Subsidize all firms after 2013	Subsidize White List firms after 2013	No subsidies after 2013
Lifetime Revenue 2014-	922	882	793
Lifetime Net Profit 2014-	712	716	656
Production Subsidy	106	70	0
Investment Subsidy	40	13	0
Entry Subsidy	0	0	0
Δ Revenue/Subsidy	85%	105%	
Δ Net Profit/Subsidy	37%	71%	

Note: this table reports discounted sum of revenue, net profit and subsidy from 2014 to 2050 in billions of 2000 constant RMB, averaged across simulations. In column 1, all firms receive production and investment subsidies from 2014 to 2050; in column 2, only (optimal) White List firms receive subsidies; in column 3, no firms receive any subsidies. The (optimal) White List includes 56 firms with the highest profitability in 2013.

Temporary vs. Permanent Subsidies We present additional Figures D6, D7 for Section 6.3 and discuss optimal policy duration. A natural question that arises with a temporary policy is the horizon over which subsidies are offered. To gain insight into the optimal horizon, we vary the length of time over which production and investment subsidies are provided, adjusting the per-unit subsidy so that the total subsidy budget is similar across all policies. Table E19 shows that the rate of return is not always monotonically increasing as the horizon is shortened. Indeed, a policy that lasts for just a single year performs relatively poorly, as shown in the first column. This is because there is little capital accumulation under such a policy. Firms face convex costs of investing in capital due to adjustment costs. If subsidies are only available for a short period of time, firms are unlikely to make large investments, even if the per-unit subsidies are large.

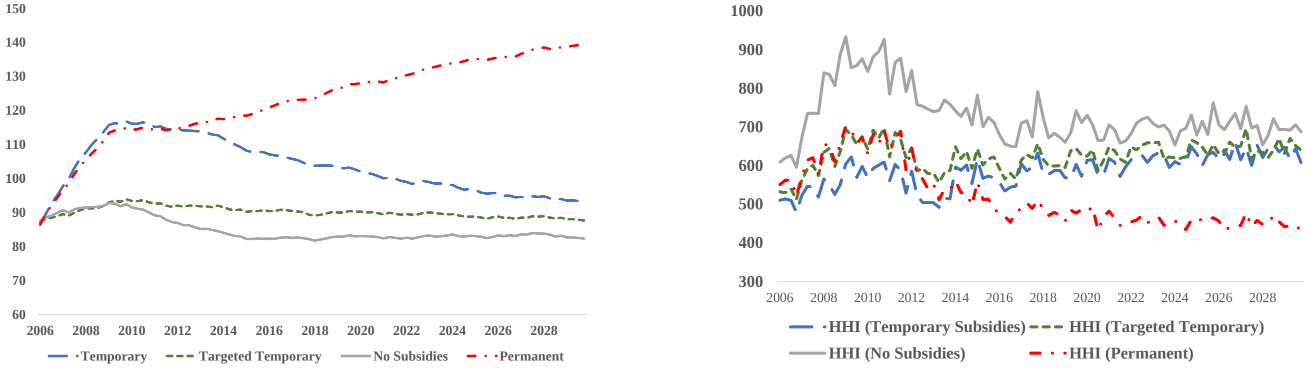
These results indicate that policymakers face a trade-off when deciding on the length of the horizon over which to implement the industrial policy. Making the subsidies temporary leads to favorable selection effects, but if the time horizon over which the subsidies are provided is too short, this leaves insufficient time for firms to take advantage of economies of scale with the help of the subsidies. In the shipbuilding industry, the optimal horizon over which industrial policy should be implemented appears to be between 3 and 5 years. In comparison, the actual industrial policy implemented by China has continued from 2006 to now, although it has undergone significant changes over time.

E Rationales for Industrial Policies: Additional Results

E.1 Perfect Competition and Strategic Trade Arguments

Here we analyze how the performance of policy instruments depends on the nature of competition. Table E20 illustrates counterfactual simulation results where we assume that firms take prices as given (per-

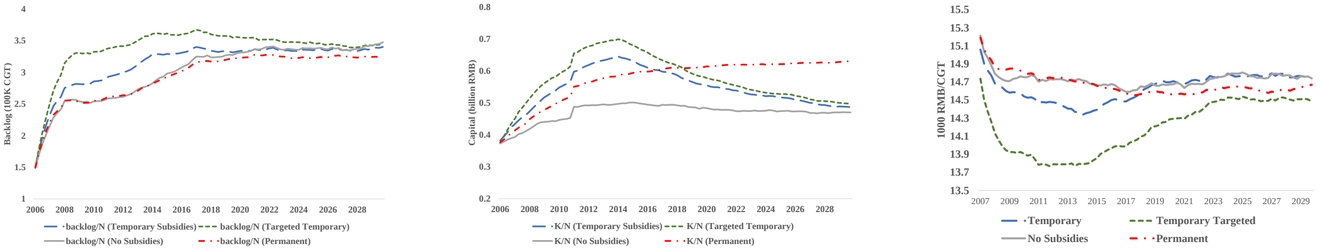
Figure D6: Number of Firms and HHI under Temporary vs. Long-term Subsidies



(a) Number of firms **(b)** HHI: Industry Concentration

Note: this figure compares temporary vs. long-term policies. The grad solid line refers to no subsidies. The green short-dashed line refers to temporary and targeted policy. The blue long-dashed line refers to the temporary policy. The red dash-dot line refers to the long-run policy. a) number of Chinese firms by year under different policies. b) HHI (industry concentration) over time.

Figure D7: Per-firm Backlog and Capital and Average Production Efficiency under Temporary vs. Long-term Subsidies



(a) Per-firm backlog **(b)** Per-firm capital **(c)** Average marginal cost index

Note: this figure compares temporary vs. long-term policies. The grad solid line refers to no subsidies. The green short-dashed line refers to temporary and targeted policy. The blue long-dashed line refers to the temporary policy. The red dash-dot line refers to the long-run policy. a) Per-firm backlog by year under different policies. b) Per-firm capital. c) Average marginal cost index is $\bar{s}_{jt}$ averaged across firms and measures firm production efficiency.

fect competition), instead of competing in quantities. Eliminating market-power considerations helps us evaluate the importance of the strategic trade argument in this setting. Relative to the benchmark results in Table 5, the overall return on subsidies is indeed lower under perfect competition, though the gap is modest. This is mainly driven by the fact that production subsidies are less effective when firms are price-takers (38% vs. 50%).

E.2 Cost Discovery

As pointed out by Hausmann and Rodrik (2003), developing countries often do not know which products they are good at producing. Some entrepreneurs and innovators incur the cost of setting up production

Table E19: Temporary Industrial Policy with Varying Horizon

	Temp. 1 year	Temp. 3 years	Temp. 5 years	Temp. 8 years	Temp. 12 years	No subsidies
Lifetime Revenue 2006-	1481	1586	1614	1655	1666	1366
Lifetime Profits 2006-	972	1000	995	980	991	853
Production subsidies	205	206	201	201	201	0
Investment subsidies	38	51	48	49	50	0
Total Subsidies	243	257	248	250	251	
Δ Revenue/Subsidy	47%	86%	100%	116%	119%	
Δ Net Profit/Subsidy	49%	57%	57%	55%	51%	

Note: In all columns except the last, firms receive production and investment subsidies for a limited number of years. For example, in column 1 (1 year), all firms receive subsidies during the year 2006; in column 2 (3 years), all firms receive subsidies from 2006 to 2008. Revenue, net profit and subsidy refer to the discounted sum from 2006 to 2050 in billions of 2000 constant RMB and averaged across simulations.

Table E20: Performance of Different Policy Instruments with Perfect Competition (in Bn RMB)

	All Subsidies	Production subsidies	Investment subsidies	Entry subsidies	Remove all subsidies
Lifetime Revenue 2006-	2253	2055	1786	1867	1716
Lifetime Net Profits 2006-	963	943	888	937	856
Production subsidies	267	227	0	0	0
Investment subsidies	78	0	42	0	0
Entry subsidies	412	0	0	217	0
Δ Revenue/Subsidy	71%	150%	166%	70%	
Δ Net Profit/Subsidy	14%	38%	74%	37%	

Note: in these simulations, firms are assumed to be price-takers and optimally choose production, investment, entry and exit. Revenue, net profit and subsidy refer to the discounted sum from 2006 to 2050 in billions of 2000 constant RMB and averaged across simulations. ΔRevenue/Subsidy and ΔNet Profit/Subsidy are defined as in Table 5.

and bear the risk of discovering the set of products that a country is good at producing. Once this knowledge is known, it can be (sometimes quickly) imitated by followers. As a result, early entrepreneurs and innovators only capture a fraction of the social value they generate. The gap between the social and private benefits of exploration justifies government intervention, such as entry subsidies to promote entrepreneurship in the first place.

Here, we evaluate the relevance of cost discovery in the Chinese shipbuilding industry in several ways. First, we perform three exercises to evaluate the importance of cost discovery by examining Chinese shipyards' production costs. Then, we quantify the effect on the returns of China's industrial policy if cost discovery were to be large.

Our exercises suggest cost discovery is not important in our context. First, we find no evidence of spillovers across Chinese firms: the pairwise correlation between ω_{jmt} (firm productivity, the residual component of marginal cost) for each pair of firms that both produce a given ship type is 0.01 for bulker producers, 0.01 for tanker producers, and 0.02 for containership producers. These results indicate that spillovers across firms are limited and that common cost shocks as a result of cost discovery are unlikely to be important. Second, we test whether firm productivity ω_{jmt} depends on past favorable shocks (either the lowest $\omega_{jm\tau}$ or the average of the lowest 10% $\omega_{jm\tau}, \tau < t$) among all Chinese firms that had produced the same ship type, as cost discovery could lower the costs of *future* firms that produce the same ship type. The estimated effect is small in magnitude and statistically insignificant. Third, under cost discovery, the more firms that produce a particular ship type, the more likely that some of them discover more efficient ways of production, and the remaining firms can observe and imitate. However, the effect of the number of past producers on current marginal costs is statistically insignificant and has the wrong sign. Taken together, these results suggest that even if cost discovery is present, its magnitude is limited in the context of the Chinese shipbuilding industry.

Our last exercise aims to examine the effect of cost discovery on the return of entry subsidies if cost discovery were to be important. We re-run the counterfactual analysis and allow the entry cost to be shifted downward after the early entrants. This mimics the social value created by early entrepreneurs. We assume that entry subsidies between 2006 - 2008 lowered the entry costs of all future entrants post 2009 by 30%, which is economically large (and significantly larger than the modest magnitude of the cost discovery effects we document above). Even so, the return on entry subsidies only increases to 44% from our baseline estimate of 32% in the absence of cost discovery.

E.3 Forcing Foreign Firm Exit

Our baseline analyses did not incorporate foreign firm exit because there were few observed exits in our sample period. Since shipyards sometimes stay idle for several years during economic downturns and become active again in future years, we collected additional data from 2014 to 2022 to evaluate foreign exits, using the Clarksons shipping register and OECD (2015).

In Japan, 20 firms exited out of 108 firms from 1998 to 2013. Out of these, only 1 firm exited between

2006 and 2008 (when China intervened most aggressively), while 10 firms exited between 2009 and 2013 (after the onset of the financial crisis and associated economic downturn). These 20 firms account for a small share of overall Japanese ship production during the sample period: about 3.6 - 4%, depending on whether we measure production in million CGT or use the number of ships. In Korea, 15 firms exited out of 46. Out of these, 1 firm exited between 2006 and 2008 and 13 between 2009 and 2013. These firms are also small and account for 1.8% of S.K.'s overall production in CGT and 3.7% in terms of the number of ships.

Thus, there were very few exits between 2006 - 2008, when the Chinese government's support for shipbuilding peaked. The vast majority of Japanese and Korean exits took place during the economic downturn following the financial crisis when both China's industrial policy and the financial crisis had likely contributed to foreign firm exits. Regardless of the causes, the benefit to Chinese shipbuilders from these exits was limited. Altogether, the foreign firms that exited after 2006 accounted for 1.6% of global production. The additional business-stealing effect as a result of Chinese shipyards taking the place of these foreign firms is small compared to our baseline estimates, where China's world market share went up from 29% to 42%, ignoring foreign firm exits.

E.4 Impact of Industrial Policy on Freight Rates and Trade

China is the world's biggest exporter and the close second largest importer behind the USA in 2019. Given its fast growth in trade volume over the past couple of decades and its prominent role in global trade today, another reason to subsidize shipbuilding during the 2000s may have been to boost its imports and exports. Indeed, a larger worldwide fleet reduces transportation costs (or freight rates) and thus increases trade; if Chinese exporters and importers face entry barriers or other frictions, these subsidies may be justifiable.

To evaluate this argument, we first assess the extent to which industrial policy reduced freight rates. We then examine how changes in freight rates induced by the industrial policy have affected China's export and imports.

Effect of Industrial Policy on Freight Rates: As ships' lifetime discounted stream of profits depends on freight rates, and prices of new ships reflect their discounted future profits (the shipping industry is competitive), we use observed ship prices to invert freight rates. A ship's lifetime profit is equal to:

$$\Pi_t = \sum_t \beta^t (P_t^f Q_t^f - C(Q_t^f)) = \sum_t \beta^t (\bar{P}^f Q_t^f - C(Q_t^f)) \tag{E9}$$

where P_t^f is the freight rate in period t, $\bar{P}^f$ is the average freight rate, Q_t^f denotes the total number of voyages undertaken by the ship in period t, and $C(Q_t^f)$ is the operating cost. We obtain estimates of operating costs from UNCTAD (2012). We use the price of a ship to approximate its lifetime expected profit, invert equation (E9) and average over our sample period to obtain the long-term steady-state freight rate as a function of ship prices and operating costs. Since our counterfactuals have calculated changes in ship prices, we can use this to evaluate changes in freight rates.

We estimate that industrial policy caused the price of bulk carriers to fall by 13.2%, leading to a decline in bulk carrier freight rates of 6.1% (Table E21). Similarly, China's subsidies reduced containership prices by 4.3%, resulting in a 2% decrease in containership freight rates.

Effect of Freight Rates on China's Exports and Imports: Next, we evaluate how this reduction in freight rates affected China's exports and imports. The key determining factor is the trade elasticity with respect to shipping costs. Brancaccio et al. (2020) estimate a trade elasticity of -1 for bulk shipping, while Jeon (2018) estimates the elasticity to be -3.9 for container shipping. As there is no available data on the breakdown of China's trade volume by transport type, we assume that 70% of China's overall trade is seaborne, following UNCTAD (2012). Since China primarily imports raw materials and commodities that are typically transported in bulk carriers, while it exports manufactured goods that are usually transported in containerships, we assume that China's imports use bulk carriers and that its exports use containerships. We ignore tankers due to the lack of the appropriate trade elasticity estimate, as well as the considerably smaller associated trade volume.

Table E21 presents the estimated impact on China's trade volume. Subsidies had led to an annual increase in the amount of US$ 57 bn for China's imports and US$87 bn for China's exports between 2006 and 2013. The total effect of the subsidies on China's trade volume was therefore $144 bn annually. In contrast, the subsidies amounted to $11.3 bn annually during the same period. Whether or not the welfare gains associated with the increased trade volume could justify the cost of subsidies is an important question; however, answering this question requires a general equilibrium trade model and thus falls beyond the scope of this paper.

Table E21: Impact of Industrial Policy on Freight Rates and China's Trade Volume

Imports	2006-13	**Exports**	2006-13
% decrease in bulk ship prices	13.2%	% decrease in container ship prices	4.3%
% decrease in bulk freight rate	6.1%	% decrease in container freight rate	2.0%
Bulk trade elasticity	1	Container trade elasticity	3.89
% change in seaborne imports	6.1%	% change in seaborne exports	7.9%
% change in imports	4.3%	% change in exports	5.5%
Impact on annual imports (US$ bn)	57	Impact on annual exports (US$ bn)	87

Note: We obtain operating cost estimates for bulk carriers and containerships from UNCTAD (2012) and use them to calculate the effect of industrial policy on freight rates. China's total export and import value comes from the UNSD Commodity Trade database. We assume 70% of China's trade (in value) is searborne, following UNCTAD (2012).

E.5 Military Production

We explore whether military considerations may have contributed to the motivations behind China's shipbuilding subsidies. Our primary sources are the yearly report known as IHS Jane's Fighting Ships, produced by the intelligence company IHS Jane's (Saunders, 2015), as well as "Chinese Naval Shipbuilding: an Ambitious and Uncertain Course", a 2017 book about the Chinese naval shipbuilding industry

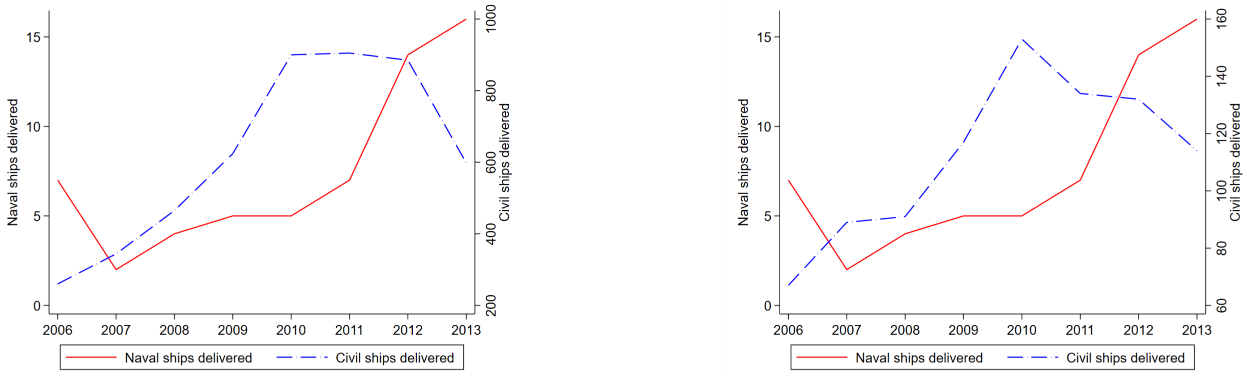
(Erickson, 2017).[9]

We focus on major combatants with significant combat capacity (advanced weapons systems, etc) and excluded smaller ships, such as fast attack craft, logistical vessels, research ships, resupply ships, and medical ships. This is partly because these smaller ships have sparse data coverage and are less advanced in their production technology.

Among the hundreds of commercial shipyards in China, only the two largest and state-owned conglomerates, China State Shipbuilding Corporation (CSSC) and China Shipbuilding Industry Corporation (CSIC), fulfilled military production through a separate entity. The military production is concentrated in thirteen subsidiaries of CSSC and CSIC, all of which are state-owned enterprises. Different shipyards produce different classes of military ships. These shipyards are typically dual-use, producing both commercial and military ships in the same complex (Erickson, 2017).

Figure E9 plots the annual deliveries of naval and commercial ships from 2006 to 2013. Panel (a) plots deliveries across all Chinese shipyards. Panel (b) plots deliveries by the 13 shipyards that produce both military and commercial ships. Both types of deliveries experienced a several-fold increase during this period, although military production appears to have accelerated after the financial crisis and continued to increase throughout the sample period. Turning to the 13 dual-use shipyards, like the rest of the commercial shipyards, they exhibited significantly higher production in both ship types, providing suggestive evidence that China's supportive policy might have benefited its military production as well. Due to the small number of observations, as well as the difficulties in verifying data coverage, we take such evidence as suggestive.

Figure E9: Deliveries of Naval and Commercial ships in 2006 - 2013



(a) All Chinese Shipyards

(b) Shipyards Producing Both Types

Note: This figure plots the number of commercial ships and naval ships delivered by Chinese shipyards over time. Source: Clarksons and IHS Jane's. a) Deliveries by all Chinese shipyards. b) Deliveries by 13 shipyards that produce both ship types.

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[9] We are most grateful to Elliott Mokski for discovering and collecting these data sources.