Redistribution in Environmental Permit Markets: Transfers and Efficiency Costs with Trade Restrictions

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Abstract

Regulators often restrict trading in environmental permit markets to pursue distributional or labor objectives, even at the cost of allocative efficiency. I evaluate the efficiency and distributional impacts of two common trade restrictions in Iceland's fisheries permit market: segmented trading by firm size and individual production requirements. Using detailed harvest and permit trading data linked to administrative records on worker employment and earnings, I first document that the introduction of permit trade increases the harvest share of productive firms by 15 percentage points but shifts income from lower- to higher-income workers and reduces aggregate labor demand by 12%. I further demonstrate that the trade restrictions, meant to counteract these labor impacts, are binding and lower productivity. I develop a joint model of production and permit trading to simulate profits, labor demand, and worker earnings in permit market equilibria without the restrictions, in order to isolate each restriction's efficiency and distributional impacts. The comparison reveals distinct goals for each restriction: Per dollar of foregone profit, segmentation increases labor demand 20 times more than the production requirement, while the production requirement redistributes 14% more income to low-income workers than segmentation. Implementing both restrictions creates more and higher-paying jobs and outperforms the production requirement alone.

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1 Introduction

Environmental permit markets are widely used to manage commons like air, water, lands, and fisheries.[1] Their appeal lies in achieving abatement targets at minimum cost by setting an aggregate cap, allocating permits, and allowing producers to trade them (Crocker 1966; Dales 1968). However, policymakers have goals beyond cost-effectiveness, such as job protection or reducing income and environmental disparities. Unrestricted trading can undermine these objectives. While the sale of initial permit allocations provides lump-sum transfers (Montgomery 1972), these benefits mainly accrue to firm owners, limiting their potential to address redistributive concerns involving workers or local communities, concerns that can drive policymakers to avoid environmental markets altogether (Grainger and Parker 2013; Newell, Pizer, and Raimi 2014; Ryan and Sudarshan 2024).

Rather than evaluating whether permit markets are desirable relative to command-and-control regulation, I study the design of permit markets given these distributional concerns. When regulators do adopt market-based policies, they often restrict permit trading to prevent production changes and to meet redistributive goals. Two common designs are to segment permit markets by producer characteristics like size or to require producers to use rather than sell a fraction of their allocated permits. Such limits are commonly proposed and implemented in permit markets in fisheries (Kroetz, Sanchirico and Lew 2015; Ho 2023), wetlands banking (Aronoff and Rafey 2024), water (Gillig et al. 2005; Hagerty 2023), and air pollutants (Fowlie and Perloff 2013; Burtraw and Roy 2023; Robertson et al 2024; Shapiro and Walker 2024). Trade restrictions in pollution markets may prevent undue pollution exposure in marginalized communities. In resource settings, trade restrictions can benefit labor by increasing employment (labor demand) or preventing the concentration of earnings. These impacts are important if workers cannot recover earnings elsewhere or shift to more productive firms, or if there is a desire to preserve a "way of life" in the commons.[2]

What are the efficiency and distributional consequences of trading limits in permit markets? Answering this question requires understanding how segmentation and produc-

[1] Roughly a fifth of global greenhouse gas emissions are covered by emissions trading schemes (World Bank, 2024). Emissions trading has been central in policies like the U.S. Clean Air Act Amendments (Schmalensee and Stavins 2019; Shapiro and Walker 2023), and about a third of fisheries operate under tradable catch share regimes (Costello et al. 2016). Payments-for-ecosystem-services programs account for around $40 billion in annual transactions globally (Salzman et al. 2014).

[2] For example, Congress passed a six-year moratorium on permit trading in America's fisheries due to the "challenge...to maintain employment and a cherished way of life in fishing communities" (NAAS 1999).

tion requirements affect equilibrium permit prices and corresponding production choices. First, I present a stylized theoretical framework to demonstrate the profit and production effects of these regulations. Segmentation creates distinct permit prices across market segments, while the production requirement rotates the permit supply curve, with each lowering the gains from trade. Answering the question also requires mapping production choices to the redistributive outcomes of interest to the regulator, in my case labor demand and worker earnings. I therefore must know how firm owners and labor split the returns from harvesting different quantities. With equilibrium production changes, profit functions, and linkages to worker outcomes, I can evaluate the cost of redistribution: the foregone profits against increased labor demand and earnings to low-income workers, in markets with trade restrictions versus ones without them.

These efficiency-distribution trade-offs are fundamental to environmental market design, as policymakers frequently debate how to alleviate losses to adversely impacted groups across different environmental challenges. I explore these trade-offs in the context of Iceland's fisheries permit market, one of the world's oldest and largest in harvest terms. Permits to harvest fish are freely allocated, but firms are restricted from selling more than half their allocation (*the production requirement*). In addition, the cap on total harvests is split between small and big boats, with no trading allowed between them (*segmentation*). The intended gains are more jobs (higher labor demand) and shifts in earnings to groups that otherwise lose out from permit trade. The production requirement supports crews on boats that might otherwise sell most of their permits, while segmentation protects small-boat crews by preventing permit sales to larger boats. These groups can be distinct depending on permit allocations, the average incomes of workers across boats of different sizes, and how profitability relates to size.

The setting provides detailed data to assess the impacts of permit trading and the trade restrictions. I combine data on daily harvests, boats, and prices; regulatory data on permit trades and allocations; and administrative records of workers' employment and earnings histories. Observing daily harvests and permit transactions reveals productivity heterogeneity while linking permit holdings to harvests and profits. Fixed crew sizes and observed revenue-sharing schemes allow me to map production choices to labor demand (person-days) and earnings.

I analyze the expansion of permit trading to small boats to assess its impact on productivity, labor demand, and income redistribution. Before 2001, small boats could not trade permits; afterward, they could trade in a segmented market with some medium-sized boats, while large boats were already in a permit market. A difference-in-differences analysis comparing small boats entering trading in 2001 to large boats already trading reveals gains from trade: boats with above-median harvests per person-day gained 15 percentage points in harvest share from less productive boats, relative to the initial permit allocation. However, as higher-productivity boats are less labor-intensive, aggregate labor demand fell by 12%. Among workers who remain in fishing, permit trading redistributed earnings from low- to high-income workers, increasing income dispersion. Low-productivity boats, which pay lower wages, lost harvests, widening the earnings gap between low- and high-income fishery workers by 25%. These effects are amplified in this setting because crew wages are tied to harvest revenue through bargaining agreements, and workers do not offset lost earnings with income outside the fishery.

Next, I examine the efficiency impacts of the two trading limits. The production requirement binds, with 16% of firm-years bunching just above 50% of their permit allocation. Bunching firms have 10% lower average daily harvests than nearby non-bunching firms, indicating increased production on labor-intensive, low-earning boats. For permit market segmentation, I find that permit prices are 30% lower on average in the small-boat market, leading to higher aggregate harvests among small boats, which are labor-intensive and have lower-income workers, than would prevail in a unified market.

The reduced-form analyses provide evidence of gains from trade, redistributive impacts, and effects of trade restrictions. Quantifying efficiency costs and isolating the impact of each restriction requires counterfactual market equilibria: how permit prices and corresponding permit choices, earnings, and labor demand change without the production requirement or market segmentation. To achieve this, I develop a joint model of permit trading and production decisions that links permit choices to prices and profits, aggregating choices to construct permit supply and demand curves. Labor earnings are tied to permit choices through revenue-sharing regimes, and labor demand is determined by the fixed crew size and the days needed to harvest the permit amount.

In the model, boats vary in profitability based on observable traits. After trading permits, they face daily cost shocks and select the highest-profit days to meet their permit quantity. Each boat's permit quantity, meanwhile, is where marginal profits equal the permit's shadow cost (permit price plus transaction costs). However, they must also harvest at least half their permit allocation. Gains from trade arise from differences in marginal profits and in permit allocations. A portion of harvest revenue goes to labor earnings and the remainder to boat owners, who also take the gains or losses from permit trade.

There are two objectives in estimating the model. The first is to estimate the permit choice function and its relationship to profits. This requires the parameters of the daily cost shock distribution and the transaction cost function. Choices of days with varying revenue identifies the variation in daily cost shocks, while the optimality condition on permit choice identifies mean daily costs. I estimate transaction costs by relating permit allocations to permit choices, conditional on boat characteristics. Due to the lack of an analytical solution for the day choice likelihood, I use the method of simulated moments (Pakes 1986) to estimate these parameters and construct the permit choice and profit functions. The second objective is to link permit choices to labor demand and earnings. Fixed crew sizes, labor earnings tied to harvest revenue, and worker-firm connections enable estimation of labor demand (person-days) and earnings in relation to harvest revenue. The revenue-earnings relationship and labor demand functions are then held fixed in alternative market designs.

I can then isolate the effect of each trade restriction by simulating counterfactual market equilibria with the estimated profit and permit choice functions. Without the production requirement, boats make an unconstrained permit choice. Without segmented markets, all boats face the same permit price. I search for the new equilibrium permit price (or prices if the market is segmented) that clears the counterfactual market at the aggregate permit supply found in the data. Differences in total profits between the market equilibrium and production at the given permit allocation gives the gains from trade. The gains from the market with restrictions are still considerable, increasing aggregate profits by 12% above a benchmark where boats are forced to harvest their permit allocation.

Comparing markets with each restriction to a simulated market without the trade restrictions, I find that segmentation reduces gains from trade by only 5% across all years despite 30% differences in permit price, as permit supply and demand are inelastic (the marginal profit curves of small boats are very flat and close in value to the medium-sized boats that increase production in the unified market). In equilibrium, the production requirement imposes a greater constraint on production, destroys more gainful trades, and lowers gains from trade by 15%.

The policies have distinct benefits. Market segmentation increases labor demand. It shifts production to smaller, more labor-intensive boats, increasing labor demand by about one person-day for every thousand dollars of foregone profit, compared to a market without trade restrictions. This effect is 20 times greater per dollar than that of the production requirement. The difference in average labor intensity between small and large boats is much larger than that between high net sellers (whose harvests increase under the production requirement) and other boats. In addition, segmentation has only half the efficiency cost. Converting person-days to estimates of jobs, I find that segmentation costs about $76 thousand per job created, well within the range of other types of government investment programs in wealthy countries and considerably lower than tariffs or "buy domestic" requirements.

Meanwhile, the production requirement is more effective at redistributing income, raising incomes for bottom-quintile workers by 14% more per dollar of foregone profit when compared to segmentation. The difference stems from segmentation benefiting small-boat workers, who are higher in the income distribution than those on boats selling much of their allocation. However, these restrictions are a costly form of redistribution: transferring a dollar from the top to the bottom half of the fishery income distribution via the production requirement costs $6.19, nearly four times the cost of redistribution through the US tax code (Hendren 2020) and roughly in line with other regulatory tools like electricity pricing (Borenstein 2011). The redistribution primarily benefits low-income fishery workers, who earn relatively high wages when working on fishing boats but have lower overall lifetime incomes. The rationale for these trade restrictions is less about efficient redistribution and more about ensuring that fisheries offer more high-earning job opportunities—often among the best-paying jobs these workers can secure in their working lives—and about preserving a threatened "way of life."

Combining the two trade restrictions outperforms the production requirement alone, increasing labor demand more while achieving similar redistribution to low-income workers per dollar of foregone profit. This approach also shifts costs, transferring losses from low-profit small-boat owners to the highest-profit boat owners, who are net buyers in the permit market and face reduced profits as permit prices rise. If job creation were prioritized over equity, segmentation alone might suffice. However, combining the policies allows regulators to balance labor demand and income redistribution, supporting both job creation and higher incomes for low-income fishery workers.

Related literature. This paper contributes to work on environmental permit market design when regulators have redistributive objectives for groups that do not directly benefit from permit trade. I focus on two common design choices—market segmentation and individual trading restrictions—and study their efficiency and distributional impacts.

The modeling approach is motivated by reduced-form evidence of reallocation following the introduction of permit trading in air pollution markets (Greenstone et al. 2022; Colmer et al. 2024) and fisheries (Costello, Gaines, and Lynham 2008; Lee and Thunberg 2013, 2019; Reimer et al. 2014; Isaksen and Richter 2018; Ardini and Lee 2018).[3] The paper builds on structural approaches that infer production costs and firm behavior from observed choices (Carlson et al. 2000; Ellerman et al. 2000; Borenstein et al. 2002; Keohane 2006; Chan 2015), as well as work that uses permit prices to assess compliance and abatement costs (Fowlie, Knittel, and Wolfram 2012; Deschenes, Greenstone, and Shapiro 2017; Shapiro and Walker 2021). While productivity gains from tradable permit schemes have been documented in fisheries (Ho 2022; Reimer et al. 2022), most existing work evaluates aggregate gains from trade rather than design-specific trade-offs.

The analysis also complements research on inefficiencies in environmental markets (Hahn 1984; Fowlie 2010; Hahn and Stavins 2011; Regnacq, Dinar, and Hanak 2016; Hagerty 2023; Aronoff and Rafey 2024), and on the role of design features such as banking and permit allocation rules (Fowlie and Perloff 2014; Toyama 2024). A smaller literature studies the production and price effects of market segmentation and production requirements in particular (Kroetz, Sanchirico, and Lew 2015; Burtraw and Roy 2023).

By highlighting heterogeneous impacts across firms and workers, this paper contributes to the literature on the distributional consequences of environmental regulation (Hsiang, Oliva, and Walker 2015; Grainger and Parker 2013; Grainger and Costello 2015; Mansur and Sherriff 2021; Hernandez-Cortes and Meng 2023), including work on employment and earnings effects of pollution regulation (Greenstone 2002; Walker 2013) and the energy transition (Colmer et al. 2023). More broadly, the paper aligns with recent research evaluating policy designs based on outcomes relevant to regulators beyond allocative efficiency (Agarwal, Hodgson, and Somaini 2020; Aspelund and Russo 2023).

[3] For historical evidence on changes in fisheries production following permit market introduction, see Arnason (1996; 2005; 2012), Mathiasson and Agnarsson (2010), and Agnarsson, Matthiasson, and Giry (2016).

Finally, the paper relates to a broader literature on regulatory design and firm responses to heterogeneous rules based on size, region, or sector (Becker and Henderson 2000; Gao et al. 2009; Bushnell and Wolfram 2012; Garicano et al. 2016; Fowlie and Reguant 2022; Ito and Sallee 2018; Costello and Grainger 2022). It extends this work by quantifying the efficiency costs and distributional gains of alternative permit market designs, in the spirit of research on the marginal value of public funds (Hendren 2016; Hendren and Sprung-Keyser 2020) and the costs of redistribution through regulatory instruments (Feldstein 1972; Borenstein 2012; Athey, Coey, and Levin 2012; Nakabayashi 2013).

2 Framework

This section presents a stylized framework to clarify how restrictions on permit trading affect efficiency and distribution in environmental permit markets. The framework isolates the key mechanisms linking permit prices, production choices, and labor outcomes, and motivates the empirical analysis that follows.

2.1 Set-up

There is a set of firms indexed by i, each characterized by $\mathbf{z}_i$, that choose production q_i from a regulated commons and earn profits $\Pi(q_i, \mathbf{z}_i)$, increasing in q_i. Aggregate production is capped at $\bar{Q}$. Each firm receives an initial allocation $\bar{q}_i$ of permits such that $\sum_i \bar{q}_i = \bar{Q}$, and permits can be traded at price r.

Firms take prices as given and harvest all post-trade permits, solving

$$\max_{q_i} \ \Pi(q_i, \mathbf{z}_i) + r(\bar{q}_i - q_i). \tag{1}$$

The solution defines firm i's **permit choice function**,

$$\frac{\partial}{\partial q_i}\Pi(q_i, \mathbf{z}_i) = r \quad \Rightarrow \quad q(r, \mathbf{z}_i), \tag{2}$$

which is strictly decreasing in r. I later allow permit choice to depend on $\bar{q}_i$ through transaction frictions.

Define firm i's **net permit position** as

$$x(r, \mathbf{z}_i, \bar{q}_i) = \bar{q}_i - q(r, \mathbf{z}_i), \tag{3}$$

which is increasing in r. Firms with $x > 0$ sell permits; firms with $x < 0$ buy permits. Aggregating individual net permit positions yields upward-sloping aggregate permit supply $\mathcal{S}(r)$ and downward-sloping aggregate permit demand $\mathcal{D}(r)$.

2.2 Permit market equilibrium and gains from trade

In competitive equilibrium, permit prices clear the market:

$$\sum_i q(r, \mathbf{z}_i) = \bar{Q} \quad \iff \quad \mathcal{S}(r) = \mathcal{D}(r). \tag{4}$$

Figure 9(a) illustrates the equilibrium permit price r^* and the quantity of permits traded Q^*. The gains from trade are given by the area between aggregate supply and demand, reflecting reallocation from firms with low marginal profits to firms with high marginal profits. These gains depend both on heterogeneity in firms' production technologies $\mathbf{z}_i$ and on the divergence between the initial permit allocation $\bar{q}_i$ and the profit-maximizing allocation.

Distributional objectives. Beyond cost-effectiveness, regulators also often care about distributional outcomes. While free permit allocations can transfer value (the resource rent) to firm owners, permit trading may impose losses on other groups. In this paper, the primary focus is labor. When firms differ in labor intensity and earnings, reallocating production toward high-profit firms can reduce labor demand and shift earnings toward higher-income workers.

I focus on two labor-related outcomes: (i) the distribution of worker earnings $w_j(q_i)$ and firm wage bills $w_i(q_i)$, and (ii) labor demand $\ell(q_i, \mathbf{z}_i)$, measured in person-days. These outcomes depend empirically on production choices and differ systematically across firms. As a result, restricting permit trade can redistribute production in ways that increase labor demand or compress earnings inequality, at the cost of foregone efficiency.

2.3 Trade restrictions

I consider two common permit market designs used to pursue these objectives: production requirements and market segmentation.

Production requirements. Under a production requirement, firm i must harvest at least $\underline{q}_i$ permits, typically defined as a fraction of its allocation. This imposes a ceiling on net permit sales:

$$\tilde{x}(r, \mathbf{z}_i, \bar{q}_i) = \min\{x(r, \mathbf{z}_i, \bar{q}_i), \bar{q}_i - \underline{q}_i\}. \tag{5}$$

The requirement constrains aggregate permit supply and rotates $\mathcal{S}(r)$ inward, as shown in Figure 9(b). Some mutually beneficial trades are prevented, generating an efficiency loss. At the same time, forcing production toward firms that would otherwise sell permits can increase labor demand and raise earnings among lower-income workers. The net effect depends on how labor intensity and earnings differ between constrained and unconstrained firms.

Segmentation. Under market segmentation, the aggregate cap is split across groups of firms, $\bar{Q}_1 + \bar{Q}_2 = \bar{Q}$, and permits cannot be traded across groups. Each segment clears at its own permit price, r_1 and r_2, which generally differ from the unified-market price r^*. Figure 9(c) illustrates the resulting equilibria.

Segmentation shifts production toward firms in the protected market, increasing labor demand and earnings there, while reducing gains from trade relative to a unified market. The magnitude of these effects depends on differences in profitability, labor intensity, and permit allocations across segments.

2.4 Empirical goal

The framework highlights how trade restrictions alter equilibrium permit prices, production, and labor outcomes. Quantifying these trade-offs requires estimating permit choice functions for heterogeneous firms and mapping permit choices to profits, labor demand, and earnings. The empirical analysis therefore combines reduced-form evidence on reallocation with a structural model of production and permit trading, allowing counterfactual evaluation of alternative market designs.

3 Data and Setting

This section describes the institutional setting and data used to assess the distributional consequences of permit trading and to implement the empirical framework.

3.1 Fisheries

Fisheries production. The analysis focuses on Iceland's groundfish fishery, the country's largest commercial fishery. Production technology is well observed. Boats constitute the main fixed input and are equipped with gear specialized by species; most vessels use one or two gear types per year. Captains choose when and where to fish, typically undertaking one- or two-day trips except for trawlers. During the study period, nearly all harvests occurred in Icelandic waters and were landed at Icelandic ports. Roughly 30 percent of boats belong to fleets owned by a single firm, a share that remains stable despite consolidation over time. Almost all processed fish is exported, and I assume boats are price-takers in global fish markets.

Labor in fishing production. Labor supply is organized at the vessel level. Crews range from two or three workers on small boats to several dozen on large trawlers. In Iceland, crews are compensated through fixed shares of harvest revenue, subject to a minimum monthly wage that rarely binds. Revenue shares are negotiated between labor unions and boat-owner associations and vary by vessel size and gear mix.[4] During the study period, a single collective bargaining agreement governed compensation (1998–2008), creating a stable and transparent link between harvest revenue and labor earnings. Throughout the analysis, I treat the wage bill–revenue relationship as given.

3.2 Iceland's permit market

Iceland's fisheries permit market is one of the largest and oldest globally, covering virtually all commercial species.

History. Figure 3 summarizes key regulatory milestones. Large vessels were permitted to trade cod permits beginning in 1991. Small boats initially faced non-tradable cod

[4]Harvest revenue is first divided between crews and owners, with the crew share partly indexed to fuel prices. The crew share is then split into rank-based portions, with captains and engineers receiving multiple shares. I assume captains are aligned with owners in maximizing daily harvest revenue.

permits and were incorporated into a permit market in 2001.[5]

Permit market design. Harvesting rights are allocated as shares of species-specific total allowable catch (TAC), initially based on historical catch. Each year, the government converts shares into annual quotas following recommendations from the Marine and Freshwater Research Institute. Permits are freely allocated to boats and can only be owned by boat owners. Both permanent shares and annual permits may be traded, though permanent shares are typically sold upon exit. The annual rental market is active: 10–20 percent of harvests use leased permits in a given year. Trades are brokered, often by retired fishermen, and permits can be exchanged across species and, to a limited extent, across years. Arnason (2005) and Gretarsson (2008) provide institutional overviews.

Production requirement. A central trading restriction is the production requirement: boats may trade at most half of their annual permit allocation. This rule reflects concerns that owners could retain permits while selling most of their harvest rights, reducing labor demand and earnings.[6] Firms owning fleets may reallocate permits internally. Additional constraints include regional approval requirements for some trades and ownership caps of 15 percent per species; the largest firms typically hold 5–10 percent. While common ownership across firms may exist (Giry et al. 2015), I do not observe these linkages.

Segmented permit markets. Small vessels (below 6 GRT) initially received non-tradable cod permits while remaining otherwise unregulated. In 2001, regulators created a segmented permit market for small boats, followed by the inclusion of medium-sized vessels (up to 15 GRT) in 2002.[7] Segmentation responded to political pressure from small-boat associations and concerns about preserving employment and access to fishing. The small-boat market receives roughly 10–15 percent of total allowable catch. While limited inter-market trading from large to small boats is permitted, such trades are rare and mostly confined to firms operating mixed fleets.[8]

[5]Other groundfish species were unregulated for small boats prior to 2001; permits for these species were assigned based on harvest history upon market entry.

[6]Similar concerns arise in U.S. fisheries, where "zombie boats"—vessels held solely for permit trading—have been documented (NOAA Fisheries 2018).

[7]Boat size is measured in GT or GRT; when measures conflict, regulators use the minimum.

[8]Seasonal coastal boats operating under day restrictions account for less than 2 percent of revenue and are excluded from the analysis.

3.3 Data

A key advantage of the Icelandic setting is the ability to link production decisions to detailed worker outcomes. I combine fisheries administrative data with tax and pay-slip records for Icelandic workers; Appendix B provides additional detail.

Harvest and production data. Regulators collect comprehensive data on every landing by Icelandic vessels. For trawlers, I supplement landing records with logbook data reporting daily harvests and crew size. Fish prices are measured as species–region–gear–month averages derived from competitive auctions and direct processor purchases, which show no meaningful price differences within bins.

Boat and crew data. I observe vessel characteristics including size, engine power, and year of construction, as well as complete ownership histories. Vessel identifiers remain fixed across ownership changes. A crew registry records daily worker assignments by vessel and rank for a subset of boats.

Permit trades and prices. I observe all permit transfers and allocations across species, along with permit rental prices reported as monthly averages from 1992 and daily prices from mid-2000 onward. Because the production requirement binds in cod-equivalent units, I also collect annual species exchange rates used to aggregate permits.

Linking to administrative worker data. The most distinctive feature of the data is the ability to link fishing activity to workers' full employment and earnings histories. Iceland maintains comprehensive administrative records from tax filings, pay slips, and censuses. I observe the complete employment histories (1981–2021) of all workers ever flagged as working on a fishing vessel, identified through sector-specific tax deductions. To benchmark outcomes, I also observe a random 10 percent sample of workers who never worked in fisheries. Firm identifiers allow me to match workers to vessel ownership and infer vessel type.[9] Much of the digitization was undertaken by Sigurdsson (2024). Appendix B details the matching procedure.

3.4 Summary statistics

Table 1 reports summary statistics for 1997, 2002, and 2012—the first year of analysis, the first year small boats could trade with medium boats, and the final year before regulatory

[9]For multi-vessel firms, I classify firms by the smallest vessel owned; mixed fleets are rare.

thresholds changed.[10]

The period is characterized by substantial consolidation: the number of firms and workers declines, particularly following the introduction of permit trading.[11] Small boats account for a shrinking share of both vessels and harvests, while medium and large vessels expand production. Total revenue rises, with a pronounced spike in 2012 due to mackerel and capelin migration.

Fishery workers are predominantly male, younger, and less educated than the average Icelandic worker. The share of foreign-born workers rises rapidly from negligible levels in the 1990s, especially outside the capital region. Fishing is a high-earning occupation: the average fishery worker earns nearly twice the national average in a given year. Small-boat workers earn closer to the national mean but exhibit weak attachment to the fishery. Roughly 43 percent earn less than 90 percent of income from fishing in a given year, and many spend only a short portion of their working lives in the sector, particularly younger trawler workers who later transition to other employment or education.

4 Evidence on Permit Market's Impact and Designs

In this section, I will give evidence of gains from trade from the introduction of permit trading to small boats. I then will investigate the efficiency consequences of the two designs: the segmented market and the harvest limitation.

4.1 Impact of introduction of permit trading

Production impacts: shift to more productive boats. The introduction of permit trade among small boats provides an empirical opportunity to isolate the impact of permit trade itself. For a few years before 2001, small-boat firms operated under non-tradable cod quotas, the major species they caught. When in the permit market, these cod permit allocations remained the same but could be traded.

I begin by dividing the boats in the small-boat permit market at the median catch per man-day each year, find the share of permits allocated to above- and below-median boats

[10] Although data extend to 2020, the segmentation threshold shifted in 2013.

[11] See Figure B1. Many exiting firms sold their permits upon exit; simulations will hold the fleet fixed. A mid-1990s vessel buy-back program also contributed to consolidation (Agnarsson 2001).

in 2000 (the final year before trading), and calculate the difference between the permit allocation share and the share of final harvest These trends are plotted in Figure 4(a).[12] After 2001, the share grows substantially: the more productive boats have almost 20 percentage points more of the harvest than they did of the permits in 2000. Production shifts exactly in the direction economic theory would expect: toward boats that harvest more for every unit labor.

How much did permit trading affect the overall labor intensity of fisheries production among these boats? Figure 4(b) plots the average man-days per ton of harvest (the inverse of the productivity measure used in sub-figure a) across years in red. It then also plots the implied average labor intensity if boats are re-weighted using their 2000 allocation share. This isolates the change in aggregate labor intensity due to changes in the harvest shares to boats of varying productivity, versus changes in productivity itself. The difference between the two measures grows over time, in line with the growing change in harvests relative to the pre-market allocation shares. Figure 4(c) shows the relative difference over time. By 2006, the shift in production due to permit trade caused average labor intensity to fall by about 12%. Permit trading made fisheries less labor intensive and therefore reduced aggregate labor demand.

Labor impacts: winners and losers. Following the introduction of permit trading, production became less labor intensive and aggregate labor demand declined. At the same time, changes in harvest allocations documented in Figure 4 have direct implications for fishery workers' earnings. I therefore compare outcomes for workers on small boats in 2001 to those on large boats, relating subsequent outcomes to the labor intensity of each worker's boat in 2000. Specifically, letting y_{it} denote earnings or employment of worker i in year t, I estimate:

$$\ln y_{it} = \alpha + \phi_t + \gamma \cdot \mathbf{1}(\text{in small boat in 2000}) + \sum_{t \neq 2000} \delta_t \cdot \mathbf{1}(\text{in small boat in 2000}) + X'_{it}\beta + \epsilon_{it},$$

where the coefficients δ_t capture differential changes in outcomes for workers on less labor-intensive boats. Controls X_{it} include birth-cohort fixed effects. I also estimate a triple-difference specification comparing workers on boats below versus above the median harvest per person-day in 2000, relative to large-boat workers.

[12] Before 2001, the differences are not exactly zero because non-cod species are not regulated and medium-sized boats (6-15 GT) were in the large-boat permit market at this time.

Figure 5(a) plots the estimated δ_t coefficients. Among workers active in the fishery in 2000, there is no statistically meaningful differential effect on average earnings between workers on more- and less-labor-intensive boats in any year. Permit trading may nonetheless increase inequality among those who remain in or enter the fishery. Figure 5(b) therefore compares average earnings of workers on high- and low-productivity boats each year, relative to large-boat workers continuously exposed to permit trading. Earnings diverge sharply after 2000, with differences increasing by roughly 30 percent as harvest revenue shifts toward high-productivity boats. Low-productivity workers experience declining relative earnings, while workers on high-productivity boats maintain earnings similar to their large-boat counterparts. The exception is the first year after permit trading, when medium-sized boats had not yet been incorporated into the large-boat market.

Panels A and B of Table 2 summarize additional outcomes for workers who were on small boats in 2000. Small-boat workers are more likely to exit the fishery, though this pattern was already present in the 1990s, and a declining share of their earnings comes from fishing. Across years, there is a clear gradient by labor intensity: workers on boats with higher harvests per person-day earn more and are more likely to remain in the fishery after 2000. Workers appear able to partially offset losses through non-fishery employment, though a full accounting would require comparing cumulative earnings across sectors.

Among workers who remain on or later join small boats, earnings losses are more pronounced. Panels C and D of Table 2 examine the cross-section of fishery workers each year. The average earnings gap widens substantially after 2001, increasing by about 1.0 million ISK relative to 2000, when the gap was 2.8 million ISK (Panel C). This widening is concentrated among boats with lower catch per person-day (Panel D). In the 1990s, earnings differences were roughly 0.5 million ISK smaller than in 2000.

These trends have clear distributional implications. Table 3 reports income and demographic characteristics for the three worker groups. Prior to permit trading, workers on low-productivity boats were relatively low-income within the fishery, averaging around the 37th percentile of fishery earnings. Their subsequent earnings losses therefore imply redistribution from lower- to higher-income workers within the commons. Nevertheless, fishing is a high-earning occupation: even low-productivity boat workers ranked above the median of the national income distribution in 2000.[13]

Finally, substantial labor market churn and widening earnings gaps coincide with compositional changes in the workforce. As shown in Table 3, workers on low-productivity boats become older on average in the 2000s, while the average age of high-productivity boat workers falls. The foreign-born share rises sharply across both groups, outpacing growth in the overall Icelandic labor market, though it was already higher among low-productivity boats in 2000. Low-productivity boats are also more likely to operate outside the capital region, implying that permit trading shifts fishery income toward urban, higher-productivity vessels. There are no meaningful differences across groups in the share of income derived from fishing.

4.2 Consequence of designs

Despite evidence of a shift to production on more productive boats, the permit market is designed to limit gains from trade, by requiring half the permit allocation to be harvested and segmenting the market between large and small boats. I next show evidence of the efficiency impacts of these designs.

Production requirement. Boats in the permit market were not permitted to trade more than half their permit allocation. Figure 6(a) shows a histogram of permit holdings post-trade relative to the permit allocations across all firm-years. There is clear evidence of bunching right above the regulatory threshold of 50%.[14] For this to have an efficiency consequence, boats right above the threshold would need to take more days at sea to reach the regulatory threshold, relative to other boats right around the thresholds. Sub-figure (b) then narrows in around the 50% threshold and produces average catch per day for boats at these thresholds, with the histogram from sub-figure (a) for reference. Boats at the bunching mass have lower catch per day than those right above or those right below, clear evidence that the production requirement binds to force some boats to harvest more than they otherwise would. Because earnings are directly tied to harvest revenue, this regulation has the effect of increasing earnings for the workers on the boats.

[13]This comparison is annual; fishery workers may have lower lifetime income if fishing is concentrated in particular years.

[14]The 8% of firm-years below 50% almost all exit in the next year, indicating either the punishment is that severe, or they planned to exit anyway.

Segmented markets. The debates around the small boats centered around an interest in protecting small-scale fishing. Figure 7(a) confirms that small boats catch less per day: the average harvest per man-day in the small-boat market is about two-thirds that in the large-boat market. This alone is not evidence of inefficiency, which is about differences in the marginal shadow cost of each permit market. The prevailing marginal shadow cost can be read from the permit rental prices in each market: if caps for species are overly generous to the small-boat market, permits in that market will trade at a discount relative to large-boat permits.

Therefore I compare permit prices from all transactions within the same species for the 10 years after the introduction of the permit market:

$$\ln(\text{Permit price of transaction } i \text{ in year } t) = \alpha + \beta \cdot \mathbf{1}(\text{small-boat market}) \tag{6}$$

$$+ \text{Species-year fixed effect} + \epsilon_{it} \tag{7}$$

where the coefficient of interest is β: the average relative difference between the permit price across all transactions, within each species-year permit market.[15] Figure 7(b) shows the results of the exercise each year. In most years, small-boat permits trade at a considerable discount of 20% to 30% relative to the big-boat permits, though I cannot reject that the permit prices are equivalent in 2006 and 2007. This indicates that in most years, the regulator allocates more aggregate harvests to the small permit market than would prevail in a unified market. Combined with the fact in Figure 6(a), the design therefore induces more labor use at the expense of some profits.

4.3 Discussion

This section has provided evidence of gains from trade in the permit market, consequences to workers, and the efficiency consequences of designs to limit permit trading. Permit trading induces harvests to shift to producers who can harvest more using fewer inputs. It lowers overall labor demand in the commons while also shifting earnings from the commons from lower- to higher-income workers. Regulators attempted to ameliorate these impacts by limiting permit trading for each boat and segmenting markets. There is evidence that the limits bind on boats, forcing more harvests on more labor-intensive boats.

[15] I ignore the species exchange provisions, where boats can shift a fraction of (mostly cod) permits into other species according to fixed exchange rates.

To quantify the exact degree to which the limits shift production and increase earnings to targeted workers requires simulating alternative market equilibria under designs where the production requirement did not bind and the permit market was unified. As the framework in Section 2 makes clear, the efficiency consequences—comparing gains from trade in the current market to the less restricted one—require the actual and counterfactual permit choice functions, with which I can construct the excesss permit supply and demand curves. One must then be able to link the permit choices to the production outcomes of interest to the regulator: the harvest profits on small boats and earnings on the boats constrained by the production requirement.

I therefore extend the stylized framework in Section 1 to capture some of the salient features of fisheries production and the Icelandic permit market.

5 Model

I develop a joint model of fisheries production and permit trading. The model expands on the firm's problem in Section 2 to capture additional transaction frictions beyond the regulatory limits and capture important elements of production in the fisheries. Together, they show how I evaluate efficiency and production consequences at the time of permit allocation before harvests, costs, and trading friction shocks are realized.

5.1 A model of permit trade

The model focuses on each year separately, with an aggregate cap of permits $\bar{Q}$, split between two markets where relevant.

Boats. Each fishing boat is indexed by i. They are differentiated in their profit function $\Pi(q_i, \mathbf{z}_i)$, which maps permit quantity q_i to profits according to observable characteristics $\mathbf{z}_i$ and in their permit allocations $\bar{q}_i$. Characteristics include the gear mix available on each boat, boat size and region. While fisheries harvests consist of many species under separate permits, I consider permit quantity along one dimension, in line with the units by which the production requirement binds. In some years, boats receive non-tradeable permits; in that case, $q_i = \bar{q}_i$ and their profits are $\Pi(\bar{q}_i, \mathbf{z}_i)$. Boats in permit markets make a choice of how many permits to hold. I consider each boat i's optimization problem separately, i.e. I do not account for joint optimization of permit or fishing decisions in fleets. This is an important simplification as fleet owners can trade permits costlessly across their boats.

Regulations and other trading frictions. Before any production decisions are made, boats in the permit market choose permits to hold for the year. I extend the simple maximization problem in (1) in Section 2 to account for the two regulated limits to trading:

1. The production requirement: boats are required to hold half their permit allocation. That is, they must hold at least $\underline{q}_i = \bar{q}_i/2$.

2. Segmentation: the permit price for each boat is a function of its size $z_i \in \mathbf{z}_i$. In particular, there is a threshold $\bar{z}$ determining the relevant permit market.

$$r_i = \begin{cases} r_1 & \text{if } z_i \leq \bar{z} \\ r_2 & \text{if } z_i > \bar{z} \end{cases} \tag{8}$$

I make two remaining adjustments in response to empirical facts about permit trade in my setting, such that boats with similar characteristics $\mathbf{z}_i$ might differ in permit choices. The Icelandic permit market lacks a centralized exchange and clearly defined trading periods within the year; boats use brokers to find willing sellers and buyers as the year progresses. Figure 3 shows clear evidence of bunching around the permit allocation, which indicates that the marginal cost of permits grows as boats choose permits farther from their allocation.

I therefore introduce transaction costs that allow permit choice to depend on permit allocations $\bar{q}_i$: I denote the transaction cost function as $TC(\bar{q}_i - q_i)$, a smooth, convex, and increasing in transaction volume $|\bar{q}_i - q_i|$. The costs need not be symmetric around $\bar{q}_i$: transaction costs can differ for buyers and sellers.

I assume that remaining variation in permit choice q_i for boats of similar characteristics $\mathbf{z}_i$ and permit allocations $\bar{q}_i$ comes from an idiosyncratic shock to the marginal cost of a permit Δ_i, drawn from a distribution F_Δ. This boat-level shock does not impact harvest profits. It summarizes differences in permit choices that affect the value of permits beyond the profitability of boats. The Δ_i shock can allow the effective marginal cost of a permit to fall below the equilibrium price.[16]

[16]Because I assume boats are price-takers in the permit market, I do not allow for market power which would introduce additional mark-ups. While permit holdings have consolidated over time in Iceland as in other fishery permit markets (Giry et al 2015), the largest firms own less than 10% of the permits in any year, and there are many market participants. I therefore do not consider permit market power a first-order concern in the setting.

Permit choices. With the addition of trading frictions, the interpretation of the equilibrium changes slightly relative to the deterministic set-up in Section 2. I want to consider a regulator assessing the value of the commons at the time of permit allocation, which I assume occurs before trading. I therefore want to consider the efficiency impacts before the trading friction shock is realized. Each boat receives its permit allocation $\bar{q}_i$, observes the market-clearing price r_i and receives the permit cost shock Δ_i. The boat the maximizes total profits under the production restriction:

$$\max_{q_i} \Pi(q_i, \mathbf{z}_i) + r_i \cdot \Delta_i \cdot (\bar{q}_i - q_i) - TC(\bar{q}_i - q_i) \text{ subject to } q_i \geq \bar{q}_i/2 \tag{9}$$

First, consider the unconstrained solution via the first-order condition, which implicitly defines the unconstrained permit choice function:

$$\frac{\partial}{\partial q_i}\Pi(q_i, \mathbf{z}_i) - \frac{\partial}{\partial q_i}TC(\bar{q}_i - q_i) = r_i \cdot \Delta_i \implies q(r_i, \mathbf{z}_i, \bar{q}_i, \Delta_i) \tag{10}$$

I then consider the permit choice function averaged over the Δ_i shock, meaning that permit choice functions are the same for boats with the same observable characteristics and permit allocation:

$$q(r_i, \mathbf{z}_i, \bar{q}_i) = E_\Delta[q(r_i, \mathbf{z}_i, \bar{q}_i, \Delta_i)] \tag{11}$$

The production requirement leads to an additional constraint, which also depends on the initial allocation. This characterizes the actual permit choice function, i.e. the solution to (9):

$$\tilde{q}(r_i, \mathbf{z}_i, \bar{q}_i) = \begin{cases} \bar{q}_i/2 & \text{if } q(r_i, \mathbf{z}_i, \bar{q}_i) \leq \bar{q}_i/2 \\ q(r_i, \mathbf{z}_i, \bar{q}_i) & \text{if } q(r_i, \mathbf{z}_i, \bar{q}_i) > \bar{q}_i/2 \end{cases} \tag{12}$$

Let the net permit position under a production requirement be

$$\tilde{x}(r_i, \mathbf{z}_i, \bar{q}_i) = \bar{q}_i - \tilde{q}(r_i, \mathbf{z}_i, \bar{q}_i, \Delta_i) \tag{13}$$

Market equilibrium. The aggregate demand and supply curves are market-specific. They are the excess permits among net sellers and excess production among net buyers, among participants in each market. For the small-boat market,

$$S_1(r) = E[\tilde{x}(r_i, \mathbf{z}_i, \bar{q}_i)|\tilde{x}(r_i, \mathbf{z}_i, \bar{q}_i) > 0, z_i \leq \bar{z}] \cdot \Pr(\tilde{x}(r_i, \mathbf{z}_i, \bar{q}_i) > 0, z_i \leq \bar{z}) \tag{14}$$

$$D_1(r) = -E[\tilde{x}(r_i, \mathbf{z}_i, \bar{q}_i)|\tilde{x}(r_i, \mathbf{z}_i, \bar{q}_i) < 0, z_i \leq \bar{z}] \cdot \Pr(\tilde{x}(r_i, \mathbf{z}_i, \bar{q}_i) < 0, z_i \leq \bar{z}) \tag{15}$$

and analogously for the large-boat market but conditioning on $z_i > \bar{z}$.

For each boat i in permit market n, the equilibrium condition then is the permit price r_n^* that equates ex-ante supply with ex-ante demand:

$$\sum_{i \in n} q(r_i, \mathbf{z}_i, \bar{q}_i) = \bar{Q}_n \iff S_n(r_n^*) = D_n(r_n^*) \tag{16}$$

The market equilibrium is then the set of permit decisions at the equilibrium price in the market:

$$\tilde{q}(r_n^*, \mathbf{z}_i, \bar{q}_i), \forall i \in n \tag{17}$$

The efficiency metric is the aggregate profits from the expected permit allocation:

$$\sum_i \Pi(\tilde{q}(r_i^*, \mathbf{z}_i, \bar{q}_i)], \mathbf{z}_i) \tag{18}$$

which is the profits for each boat under the expected permit allocation at the equilibrium price. In years in which some boats are given non-tradeable permits, the profits are measured at the allocated permits.

Alternative designs and equilibria. The framework in Section 2 shows that one can characterize the efficiency impacts of the permit trading rules by using the permit choice functions of firms and constructing new supply and demand functions. In particular,

1. The production requirement: solve for each boat's expected net permit position using the unconstrained permit choice function:

$$x(r_i, \mathbf{z}_i, \bar{q}_i) = \bar{q}_i - q(r_i, \mathbf{z}_i, \bar{q}_i) \tag{19}$$

   and construct the ex-ante supply and demand curves in (14) and (15) but using $x(r_i, \mathbf{z}_i, \bar{q}_i)$. Find the new equilibrium in each market where ex-ante supply and ex-ante demand meet.

2. Segmentation: find the sum of the supply and demand curves of each market n, weighted by the population in the market, i.e.

$$\mathcal{S}(r) = \sum_n S_n(r) \text{ and } D(r) = \sum_n D_n(r) \tag{20}$$

and the new equilibrium r^* is characterized by the intersection of total excess supply and demand: $\mathcal{S}(r^*) = D(r^*)$.

The two can be combined, where one constructs the total supply and demand curves using the unconstrained permit choice function.

5.2 A model of fishery production

I now turn to the construction of the profit function $\Pi(q_i, \mathbf{z}_i)$ which maps post-trade permit holdings to value. Fisheries production is characterized by choices of days at sea over uncertain harvest quantities. I outline a model of day choice where, after permit trading, boats receive shocks to the daily cost of production throughout the year and choose a harvest schedule that will allow them to harvest permits in expectation.[17]

Input choices: labor. Fisheries production is characterized by two important inputs: days at sea and the crew. The evidence suggests that, within narrowly defined categories of gear mixes throughout the year and boat size, production is Leontief in days and labor: a given production quantity requires a set number of days at sea and a number of people to serve the crew of the boat. Therefore, demand for labor (person-days) is determined in a straightforward way in this setting.

Boats of characteristics $\mathbf{z}_i$ have a defined crew size $L(\mathbf{z}_i)$. Consider a day choice function $D(q_i, \mathbf{z}_i)$ that maps permit holdings to total days at sea. **Labor demand** is the number of person-days of production, i.e. the chosen number of days at sea multiplied by the

[17]Fisheries economists have pointed to many other details of fisheries production that can determine value conditional on observable boat characteristics, including the access and use of information (Englander, 2024), congestion and the decision of where to search (Huang and Smith, 2014), and differential targeting of valuable species (Smith, 2012). There is a long literature in fisheries economics on models of location and species choice (e.g. Smith and Wilen 2003; Huang and Smith 2014; Birkenbach et al 2020). These margins carry over to the Icelandic setting; however, permit market cover boats the vary greatly in observable characteristics and behaviors and along these other margins. Because I aim to focus on the broad goals regulators bring to the design of permit markets and the link to labor supply in the fisheries, I will necessarily abstract from many particular production margins.

crew size of the boat. Therefore for given permit holdings, labor demand is

$$\ell(q_i, \mathbf{z}_i) = L(\mathbf{z}_i) \cdot D(q_i, \mathbf{z}_i) \tag{21}$$

Labor demand is therefore pinned down by the day choice $D(q_i, \mathbf{z}_i)$ to which I turn next.

Input choice: days at sea The days of the year are indexed by t with T possible days. Given permit holdings q_i, boats make a choice of days: the vector of choices is $\mathbf{d}_i$ where $d_{it} = 1$ if day t is chosen. The total number of days of production is $D(q_i) = \sum_t d_{it}$. The boat forms expectations over daily revenue and daily harvests with information set $\mathcal{I}_i$. Therefore expectations are formed for

1. The number of permits that would be harvested on a given day q_{it}. I define expected quantity for boat i on day t as $E[q_{it}|\mathcal{I}_i]$.

2. The revenue from fishing on a given day R_{it}. I define expected revenue for boat i on day t as $E[R_{it}|\mathcal{I}_i]$.

Daily revenue is not just price times permit quantity because there are unregulated species. It is the aggregate across all possible species, multiplied by the market price for each species at that time. These are the gains to fishing on day t.

The cost for i of fishing on day d is $c_{it} > 0$, which are revealed after permit trading. I assume that daily costs c_{it} are drawn independently from a distribution conditional on characteristics $\mathbf{z}_i$. Call this distribution $F_{c|\mathbf{z}}$, and the vector of cost draws $\mathbf{c}_i$.

With post-trade permit holdings q_i, boats choose the days that maximize expected profits. That is, they will choose the highest-profit days until they harvest their permit holdings in expectation. Appendix Section A outlines the day selection process formally. I denote $\mathcal{S}(q_i, \mathbf{c}_i)$ to be the set of days of highest profit until harvests equal permit holdings for a given draw of costs $\mathbf{c}_i$.

Building the profit function. In the model, permit trade occurs before costs c_{it} are realized to make day choices. The **ex-post profit function** is the profits from the chosen days, after cost shocks are revealed:

$$\tilde{\Pi}(q_i, \mathcal{I}_i, \mathbf{c}_i) = \sum_{t \in \mathcal{S}(q_i, \mathbf{c}_i)} E[R_{it}|\mathcal{I}_i] - c_{it} \tag{22}$$

and the **ex-ante profit function** takes the average across daily cost draws:

$$\Pi(q_i, \mathbf{z}_i) = \int \tilde{\Pi}(q_i, \mathcal{I}_i, \mathbf{c}_i) \cdot dF_{c|\mathbf{z}} \tag{23}$$

where I supress dependence on the information set. This is the producer surplus at the time of permit trade, before within-year shocks are realized.

5.3 Identification

I observe day choices $\mathbf{d}_i$, *realized* revenues R_{it} and quantities q_{it} on days boats did go out to fish, permit choices q_i allocations $\bar{q}_i$, boat characteristics $\mathbf{z}_i$, and day characteristics $\mathbf{z}_t$.

Revenue and quantity expectations. I specify each boat i's information set $\mathcal{I}_i$ to be the characteristics I observe $\mathbf{z}_i$ and some seasonal indicators $\mathbf{z}_t$. If forecast errors are independent of production costs, then I can identify expected revenues and quantities from regressing realized revenues and quantities on $\mathbf{z}_i$ and $\mathbf{z}_t$. Appendix A has more details.

Identifying costs with quantity constraints. The object of interest is the cost distribution $F_{c|\mathbf{z}}$, from which I can generate the ex-ante profit function. Define $F_{c|\mathbf{z}}(\mu^c(\mathbf{z}_i), \sigma^c(\mathbf{z}_i))$ as the location $\mu^c(\mathbf{z}_i)$ and scale parameters $\sigma^c(\mathbf{z}_i)$ of the cost distribution for some boat. These are functions of boat characteristics $\mathbf{z}_i$.

I assume that daily costs c_{it} are drawn independently from the cost distribution $F_{c|\mathbf{z}}$. If boats were not constrained to match their permit holdings q_i, $F_{c|\mathbf{z}}$ would be identified directly from the probability of fishing at different expected daily revenues; variation in expected daily revenues traces out values of the CDF of daily costs for each boat each year.

If boats will always meet a fixed quantity q_i, then optimality of day choices alone identifies only the scale parameter $\sigma^c(\mathbf{z}_i)$ of the cost distribution, not the location. The intuition is the same as in the basic static discrete choice model (Train 2009). Boats will always choose the most profitable days until they hit their quantity constraint, and only relative returns matter for the choice of particular days.[18]

[18] To see this, consider a boat observed to choose day 1 with revenue R_1 but not day 2 with revenue R_2, where either day alone can meet the permit holdings. There is the mean daily cost $\bar{c}$ and a cost shock ϵ_t. The choice reveals that

$$R_1 - \mu^c(\mathbf{z}_i) - \epsilon_1 \geq R_2 - \mu^c(\mathbf{z}_i) - \epsilon_2 \iff \epsilon_2 - \epsilon_1 \geq R_2 - R_1$$

Instead, the optimality of permit choices q_i for boats in the permit market reveal information about mean costs. To show this, first note that the same days will be chosen to meet a quantity goal, regardless of the mean $\mu^c(\mathbf{z}_i)$. That is, the set of chosen days $S(q_i, \mathbf{z}_i, \mathbf{c}_i)$ is the same for any $\mu^c(\mathbf{z}_i)$ and therefore can be rewritten as $S(q_i, \mathbf{z}_i, \varepsilon_i)$. The ex-ante revenue for a given quantity q_i therefore depends only on the scale parameter $\sigma^c(\mathbf{z}_i)$, as well as a portion of the production costs that varies across days. Let the vector of cost shocks $\epsilon_{it} = c_{it} - \mu^c(\mathbf{z}_i)$ (with the vector denoted as ε_i). Then I can rewrite the ex-post profits into three functions:

$$\Pi(q_i, \mathbf{z}_i, \mathbf{c}_i) = \sum_{t \in S(q_i, \mathbf{z}_i, \varepsilon_i)} E[R_{it}|\mathcal{I}_i] - \mu_c - \epsilon_{it} \tag{24}$$

$$= \sum_{t \in S(q_i, \mathbf{z}_i, \varepsilon_i)} E[R_{it}|\mathcal{I}_i] - \sum_{t \in S(q_i, \mathbf{z}_i, \varepsilon_i)} \epsilon_{it} - \mu^c(\mathbf{z}_i) \cdot D(q_i, \mathbf{z}_i, \varepsilon_i) \tag{25}$$

$$= R(q_i, \mathbf{z}_i, \epsilon_i) - c(q_i, \mathbf{z}_i, \varepsilon_i) - \mu^c(\mathbf{z}_i) \cdot D(q_i, \mathbf{z}_i, \varepsilon_i) \tag{26}$$

Then, ex-ante profits integrates over the possible cost shocks:

$$\Pi(q_i, \mathbf{z}_i) = R(q_i, \mathbf{z}_i) - c(q_i, \mathbf{z}_i) - \mu^c(\mathbf{z}_i) \cdot D(q_i, \mathbf{z}_i) \tag{27}$$

The three functions are invariant to changes in $\mu^c(\mathbf{z}_i)$, a similar intuition to how consumer surplus can be calculated up to a constant with logit demand (Train 2009).

Then, consider the unconstrained optimality condition (12), i.e. permit choice with no production restriction:

$$\frac{\partial}{\partial q_i}\Pi(q_i, \mathbf{z}_i) = \frac{\partial}{\partial q_i} TC(\bar{q}_i - q_i) + \Delta_i \cdot r_i \tag{28}$$

$$\iff \frac{\partial}{\partial q_i} R(q_i, \mathbf{z}_i) - \frac{\partial}{\partial q_i} c(q_i, \mathbf{z}_i) - \mu^c(\mathbf{z}_i) \cdot \frac{\partial}{\partial q_i} D(q_i, \mathbf{z}_i) = \frac{\partial}{\partial q_i} TC(\bar{q}_i - q_i) + \Delta_i \cdot r_i \tag{29}$$

The transaction cost function $TC(\bar{q}_i - q_i)$ is common to all boats, and permit price r_i is observed. Therefore the mean cost is identified among boats of the same characteristics $\mathbf{z}_i$. One cannot identify mean costs from the boats outside the permit market, who are given non-tradeable quotas. Instead, I will extrapolate from the permit market boats.

Identifying market parameters. The (marginal) transaction costs is a non-linear function of permit transaction volume, i.e. the magnitude between final permit holdings and

which gives information about $\sigma^c(\mathbf{z}_i)$ but not $\mu^c(\mathbf{z}_i)$.

the permit allocation. The permit cost shock Δ_i represents any other unobserved determinants of permit choice, e.g. search frictions. It is therefore crucial to include detailed heterogeneity in the profit functions $\Pi(q_i, \mathbf{z}_i)$ in order to rule out permit choice differences due to differences in harvest profitability.

I assume that Δ_i is independent of the permit allocation $\bar{q}_i$. The assumption rules out boat-specific heterogeneity in how permit allocations impact permit choice. For boats not at the constraint of permit holdings, the transaction cost function is identified from the variation between marginal profits and permit allocations, and any residual variation conditional on $\bar{q}_i$ identifies Δ_i.

Boats at the production constraint, meanwhile, bunch at constrains permit decisions such that a group of boats that bunch at 50% of their permit allocation. Because q_i is decreasing in Δ_i, each boat has a threshold $\bar{\Delta}_i$ that places them at 50% of their allocation:

$$\bar{\Delta}_i = \frac{1}{r_i} \cdot \left(\frac{\partial}{\partial q_i} \Pi(\bar{q}_i/2, \mathbf{z}_i) - \frac{\partial}{\partial q_i} TC(\bar{q}_i/2) \right) \tag{30}$$

$$\text{such that } \Delta_i > \bar{\Delta}_i \implies q_i = \bar{q}_i/2 \tag{31}$$

The transaction cost function and mean cost are identified from unconstrained boats, and therefore the threshold $\bar{\Delta}_i$ can be identified. The propensity to bunch at 50% of the allocation reveals the cumulative distribution function at $\bar{\Delta}_i$:

$$\Pr(q_i = \bar{q}_i/2) = 1 - F_\Delta(\bar{\Delta}_i) \tag{32}$$

Identifying the labor demand and labor earnings function. I lastly require two functions of interest to regulators: the relationship between labor demand and harvests and that between total labor earnings and harvest revenue. I observe crew sizes on each day L_{it}. The main determinants of crew size are size and gear choice. The latter can vary throughout the year for boats using a mix of gears (e.g. handline and gillnets). In addition, there is more heterogeneity in crew size on larger boats, conditional on flexible functions of size and gear mix. Therefore I assume that any remaining variation in crew size is independent of day choice. I can then estimate $L(\mathbf{z}_i)$ via regression of crew sizes on $\mathbf{z}_i$ and construct labor demand (person-days).

I can identify labor earnings under a similar assumption. I observe the joint distribution of annual labor earnings y_{ij} for each worker j in a *firm* and the firm's harvest revenue.

Thus, the worker's boat is not observed for firms with fleets, and it is not possible to report worker's days at sea or boat because not all workers appear in the crew registry.[19] I know that earnings are paid out in shares of harvest revenue that depend on complex formula of workers' experience, the gear mix, the size of the boat, and the type of species. I therefore assume that unobserved determinants of the wage bill are independent of harvest revenue and regress the firm's wage bill on harvest revenue.

5.4 Remarks

Table 4 summarizes the parameters of interest from the model. The model allows me to estimate profitability under substantial heterogeneity of harvest technologies, different regulatory regimes that restrict quantities at the boat level. In encompassing this heterogeneity and focusing on permit market designs, I abstract from some aspects of both the production process and Iceland's permit market. For example, I ignore any optimization within fleet; about 30% of boats are in fleets where firms might shift permits costlessly across them.

Importantly, I rule out boat-specific profitability differences: permit demand is based only on ex-ante differences in profitability by observable characteristics $\mathbf{z}_i$. I then assume that any boat-level differences in marginal profits, conditional on permit price and permit allocation, are idiosyncratic in Δ_i and do not affect profits. In reality, Δ_i could reflect boat-specific differences in profitability rather than idiosyncratic shocks to the marginal value of permits.

Second, I assume a single period of trading before production shocks are revealed. In reality, trading occurs throughout the year by a search process run by brokers, followed by an opportunity to bank permits into the next year, pull them up, or exchange different species up to a limit.[20] I assume that these balancing schemes are only used to meet the realized harvest shocks. In addition, there is some evidence of price dispersion throughout the year, though 92% of the permit price variation across transactions is across years rather than within them.[21]

[19] It is vanishingly rare for workers to work in multiple boats within the same firm, in years when all boats register all crews in the crew registry after 2011. Workers do sometimes report earnings from multiple fishing firms, but this is observable.

[20] Up to 15% of permits can be banked into the next year. Up to 5% of permits can be pulled from the next year. Permits for cod can be exchanged for permits of other species, but not vice versa, up to a certain fraction of initial allocation.

[21] See Appendix Section A.4 for a discussion of price dispersion

I model permit choices and production within a static annual framework. This approach should be interpreted as a reduced form of within-season adjustment: boats make permit and production decisions based on expected prices and profitability, while day-to-day shocks are absorbed through flexible timing of fishing activity. Annual permit prices are stable and publicly observed, and most regulatory constraints operate at the yearly level. For the policy questions considered—how trading limits shape equilibrium allocations and distribution across firms and workers—this static representation captures the relevant margins while preserving tractability for counterfactual analysis. Placing permit trading throughout the year or at the end would require taking account of a boat's evolving expectations of its permit status and/or explicitly modeling the banking decision in order to generate an equilibrium, end-of-year permit price. I avoid the computational complexity of this dynamic decision in my static framework but do not allow for gains from trade from stochastic production within the year. I capture a lion's share of the heterogeneity in production: regressing annual harvests on the characteristics $\mathbf{z}_i$ I use to determine profits (year-gear mix-size) gives an R^2 of 96%.

I also assume a static day choice decision and therefore do not consider price uncertainty within the year or updates as harvest shocks are revealed. Day choices, too, might depend on past harvests or species targeting; any decision that deviates from choosing the highest expected revenue days would be rationalized by high cost draws.

Lastly, throughout the counterfactual simulations, labor impacts should be interpreted as within-fishery, gross effects rather than net economy-wide employment changes. Permit trading reallocates harvests across vessels with different labor intensities and wage structures, changing the number of fishing days worked and the distribution of earnings among fishery workers. These effects capture the primary margin of concern for regulators in this setting, where fishing wages are tied to harvest revenue and workers have limited short-run opportunities to offset lost earnings elsewhere. I do not consider exit decisions by firms or changes to boats in response to different counterfactual designs. I hold the boat size distribution fixed everywhere, but changes to boat size could be an important margin of efficiency gains in a unified permit market, for example. These are important production decisions during my study period: there is a significant drop in firms throughout the period and particularly after their boats are placed in the permit market. Boats sell their permanent rights to permits upon exit.[22]

5.5 Estimation

Estimation proceeds in steps following from the identification argument. I first estimate expected daily revenue and quantities as an input into the estimation of a parametric daily cost distribution. These allow me to form the ex-ante profit functions and estimate the determinants of permit demand.

First step: estimate expected daily revenue and quantities. I assume that the information sets $\mathcal{I}_i$ with which boats form expectations include characteristics $\mathbf{z}_i$ (size, age, region) and monthly indicators $m(d)$. I can then estimate daily expected quantities and revenues by linear regression:

$$\ln q_{id} = \alpha_q + \mathbf{z}_i' \cdot \beta_q + \phi_R^{m(d)} + \xi_i^q \tag{33}$$

$$\ln R_{id} = \alpha_R + \mathbf{z}_i' \cdot \beta_R + \phi_R^{m(d)} + \xi_i^q \tag{34}$$

where $\mathbf{z}_i$ includes the logarithm of boat size and the region of the boat's home port, and $\phi^{m(d)}$ represent month fixed effects. I then exponentiate predicted values from these regressions to give estimated expected harvests and revenues.

Daily harvests q_{id} are measured in cod-equivalent units, where I aggregate expected landings each day according to the species exchange rates determined by regulation. The values then reflect how many permits need to be harvested by i in each day t. Daily revenue measures are formed by aggregating revenues for all species, whether regulated or not. In the model, permit holdings should match expected aggregate harvests, since boats choose days to match their post-trade permit holdings. The model-derived expected harvests scales with observed permit holdings on average, but the model-derived values are on average 9% higher. This reflects the fact that actual permit trading in the data occurs dynamically throughout the year as harvests are realized and that boats are able to bank permits. It might also

[22]In addition, there is evidence of bunching beneath the size threshold defining small boats (i.e. at 6 GT and then at 15 GT once all boats are in the permit market).

Second step: estimate daily cost distribution from day choices. With expected daily revenues and quantities, I can turn to the day choices to estimate the daily cost distribution $F_{c|\mathbf{z}}$. In this step, I estimate both the mean and variance of the cost draws. Conditioning on the permit choice q_i, I allow boats only to pick among positive-profit days. The condition that all chosen days have positive profits is an implication of the optimality of permit choice q_i and identifies mean costs.

I parameterize the daily cost distribution $F_{c|\mathbf{z}}$ as log-normal with location parameter $\mu(\mathbf{z}_i)$ and scale parameter $\sigma(\mathbf{z}_i)$. In particular, they are gear-mix-specific functions of boat size. If g is the gear mix of the boat, then

$$\mu(\mathbf{z}_i) = \alpha_1^g + \alpha_2^g \cdot \log(\text{boat size}) \tag{35}$$

$$\sigma(\mathbf{z}_i) = \alpha_3^g + \alpha_4^g \cdot \log(\text{boat size}) \tag{36}$$

There are six gear mixes g, so each year has 24 parameters. The probability of choosing a day at sea is the probability that the day is among the most profitable days up until the boat reaches its permit holdings q_i and that those days are all of positive profits. This does not have an analytical solution, and simulating choice probabilities for each day is computationally burdensome. I therefore estimate the cost parameters by the method of simulated moments (Pakes 1986; McFadden 1989). I use the observed ranked order of daily revenues and the aggregate number of days as moments. The steps are available in Appendix Section C.

Third step: calculate the profit function. With estimates of the cost parameters, I can integrate over the estimated cost distribution $\hat{F}_{c|\mathbf{z}}$, for any quantity goal q_i and boat characteristics $\mathbf{z}_i$. I also create the ex-ante day choice function $D(q_i, \mathbf{z}_i)$, i.e. the expected number of days before cost shocks are realized, to estimate labor demand. I calculate the profit function across a grid of possible permit holdings q_i and boat sizes by simulating from the estimated cost distributions for a boat of characteristics $\mathbf{z}_i$. The steps are available in Appendix Section C.

Fourth step: estimate market parameters. With the profit function $\Pi(q_i, \mathbf{z}_i)$, I can estimate the transaction cost function $TC(\bar{q}_i - q_i)$ and the distribution of permit cost shocks $F_\triangle$. Following Toyama (2024), I assume the following functional form for the transaction cost function:

$$TC(\bar{q}_i - q_i) = \frac{1}{1+\eta}\exp(\alpha + \beta \cdot \mathbf{1}(q_i < \bar{q}_i)) \cdot \mathbf{1}(q_i < \bar{q}_i) \cdot |\bar{q}_i - q_i|^{1+\eta} \tag{37}$$

which is smooth at $q = \bar{q}$. I allow for level differences in the transaction costs for buyers and sellers β. The marginal transaction cost is therefore

$$\frac{\partial}{\partial q_i} TC(\bar{q}_i - q_i) = \text{sgn}(\bar{q}_i - q_i) \cdot \exp(\alpha + \beta \cdot \mathbf{1}(q_i < \bar{q}_i)) \cdot |\bar{q}_i - q_i|^{\eta} \tag{38}$$

where $\text{sgn}(\bar{q}_i - q_i)$ is the sign function for the net permit position, such that it is positive for sellers and negative for buyers. The three parameters (α, β, η) define the transaction cost function. I parameterize F_Δ as a log-normal distribution with location parameter μ_Δ and σ_Δ and estimate the parameters via maximum likelihood. Away from the bunching threshold, Δ_i is point-identified. The likelihood contribution of the firms bunching at 50% of their permit allocation is the probability of being above the threshold $\bar{\Delta}$. Appendix Section C outlines the steps in detail.

Labor demand. Given the independence assumption on the unobserved determinants of crew size, I regress crew sizes on gear mix g-specific functions of log size, for each year:

$$L_{it} = \alpha + \phi^g + \beta^g \cdot \ln(\text{Boat size}) + \epsilon_{it}^L \tag{39}$$

The predicted values of this regression is $L(\mathbf{z}_i)$. I then scale the day choice function to find the ex-ante labor demand for each boat i:

$$\ell(q_i, \mathbf{z}_i) = L(\mathbf{z}_i) \cdot D(q_i, \mathbf{z}_i) \tag{40}$$

I also estimate the ex-ante wage bill function via a regression of wage bill w_i on single-boat firms, where I can condition flexibly on $\mathbf{z}_i$:

$$w_i = \alpha + \phi^g + \beta^g \cdot \ln(\text{Boat size}_i) + (\gamma + \phi^g + \delta^g \cdot \ln(\text{Boat size}_i)) \cdot R_i + \epsilon_i^R \tag{41}$$

which relies on variation in total harvest revenue R_i conditional on boat size and gear mix. The predicted values then give the ex-ante wage bill $w(q_i, \mathbf{z}_i)$.

5.6 Results

I estimate parameters for each year from 1999 to 2003.

Cost parameters. Panel A of Table 5 shows estimates of average cost (total estimated cost per kg output) aside the average revenue for different boat characteristics. Generally, larger boats have higher costs, though the average cost per unit output is lower, reflecting well-known scale economies in fisheries production (Ho 2023). It also shows that the mean annual cost of boats across the 7 gear types for three years, compared to mean annual revenue; costs are much lower, an indication of the low variable costs in fishing. However, the average profit per kg (revenue minus costs) varies considerably by gear mix. That is, shifting production can be valuable for lower daily costs to harvest but also because the quality (ISK per kg) of the output might be higher. Generally, costs are much higher for trawlers, though this might in part reflect a bias from taking multi-day trips.

Market parameters. Panel B of Table 5 shows estimates for the market parameters for three of the years. First the distribution of Δ is very wide and not centered at 1, indicating wide dispersion in marginal profits unexplained by distance from the permit allocation or permit rental price. Further refinements of the profit function estimation could ameliorate some of this residual. Appendix Section C.5 has details on model fit. The model is able to fit observed permit holdings very closely, despite vastly simplifying the actual permit trading behavior that occurs throughout the year, except for boats with the lowest permit holdings and allocations. I also systematically under-predict permit holdings among small boats, indicating that it might be important to allow for variation in transaction costs or the Δ_i distribution by boat characteristic.

Labor. Table 5 shows the results of regressing the total wage bill on harvest revenue at the firm level. The time period is from 1996 through 2007, covering my period of focus and the period of the major collective bargaining agreement determining crew shares. Year fixed effects control for fuel price changes, which do impact the share given to labor. I include specifications with and without firm fixed effects; meaningful differences with firm fixed effects could indicate important unobserved variation in the revenue-sharing function. Specification (2) with firm fixed effects relies on across-year variation in revenues within the same firm. The predicted values from both regressions give estimates of the labor share of revenue between 21% and 39% (the 10-90 range). A back-of-the-envelope calculation from the shares in the collective bargaining agreements indicates that about a third of harvest revenues go to crews, roughly in line with these values. Harvest revenues absorb considerable variation in the wage bill across firms, though about 10% remains unexplained. This might be due to provisions for higher shares for workers with more experience on some types of boats, variation within the year in fuel prices causing changes in shares, payouts of minimum earnings if a certain harvest revenue is not reached, or variation in the number of ranked positions (engineer, first mate) that receive extra shares.

6 The Value of Permit Trading and Counterfactual Designs

With estimates of profit functions and the market parameters in hand, I can simulate permit choice functions and estimate the gains from trade in the permit market. I can also consider market equilibria under alternative designs that remove the trading limits. This will generate new permit choices and therefore change the production outcomes of interest to the regulator.

6.1 Computing counterfactual supply and demand curves

The estimated parameters allow me to construct individual permit choice functions for all boats i in every permit market with and without the production requirement and under any permit price. I assess the following counterfactuals:

1. No production requirement: Remove the bunching at 50%, in both big- and small-boat markets.
2. Unified market: place all boats in one market starting in 2001.
3. Both a unified market and no production requirement

From these permit choices, I can construct the aggregate permit supply and demand curves underpinning the welfare analysis in the framework I outline. Specifically, I calculate permit choices for all boats in each market under a grid of permit prices. I then take the difference with the permit allocation to find whether the boat has excess demand (more permits demanded than allocated) or excess supply (fewer permits demanded than allocated) at that permit price. I then sum the excess demand and excess supply among all boats in the permit market.

I use a simple algorithm to search for the precise equilibrium permit price in the alternative markets. For each candidate price, I calculate each boat's expected permit choice, sum them to find the aggregate permit holdings, and shift to a new candidate in the direction that will allow the market to clear, i.e. for the aggregate permit holdings (i.e. the total allowable catch) to match the aggregate amount in the data each year. The steps are described in Appendix Section D. The alternative permit choices can be directly mapped to labor demand and the wage bill using the estimated relationships. Harvest profits, too, can be calculated.

6.2 Designs' impact on gains from trade

Figure 8 presents empirical analogues of the stylized framework for a representative year; results for other years appear in Appendix D. Panel 8(a) shows the equilibrium under the actual permit market design, which combines market segmentation with a production requirement. The small-boat market (red) has a substantially smaller cap than the large-boat market (blue), shifting it closer to the origin. Despite these restrictions, the figure confirms the presence of gains from trade, given by the areas under each supply curve and above each demand curve. Comparing aggregate profits at the market equilibrium (34.6 billion ISK) to profits if each boat harvested only its permit allocation (30.9 billion ISK), permit trading increased total profits by 3.69 billion ISK in 2003—about 12 percent (Table 6, column 1).

Figure 8(a) also highlights the efficiency cost of segmentation, represented by areas ABC and DEF. These correspond to foregone profits relative to a simulated unified market. In 2003, segmentation reduced gains from trade by approximately 270 million ISK, or 7 percent of total gains. The magnitude of this effect varies across years. In 2002, for example, segmentation reduced gains from trade by only about 1 percent despite a similar permit price difference (20.9 ISK), reflecting particularly inelastic permit supply and demand in the small-boat market that year.

Figure 8(b) isolates the effect of the production requirement by simulating a unified market subject to the requirement. The inward rotation of permit supply is evident, with area ABC capturing the resulting efficiency loss. In 2003, the production requirement reduced gains from trade by 760 million ISK, or 16 percent. In earlier years such as 1999 and 2000, the requirement bound on a larger share of firms and reduced gains from trade by as much as 32 percent.[23]

Figure 9 compares gains from trade across market designs by sequentially removing each restriction relative to the benchmark of a unified market without a production require-

[23] This pattern may reflect differential trends in costs and revenues across boat types or adjustments in permanent permit holdings to avoid proximity to the 50 percent threshold. In practice, permanent permits are typically sold upon exit.

ment. Removing the requirement in the segmented market increases gains from trade by 720 million ISK, while unifying the market adds an additional 310 million ISK. Together, the two trade limits therefore eliminate roughly one quarter of the potential gains from trade in 2003.

Pooling results across all years, column 1 of Table 6 reports gains from trade for four market designs: the unrestricted benchmark, each restriction in isolation, and the actual design combining both. Segmentation reduces gains from trade by about 5 percent, while the production requirement is roughly three times more costly, reducing gains by about 15 percent. The relatively small efficiency loss from segmentation—despite large differences in permit prices—reflects the shape of permit supply and demand. At the prevailing caps, marginal profit differences between small boats that sell permits in a unified market and larger boats that expand production are modest, resulting in relatively flat marginal profit curves.

A simple decomposition helps clarify these patterns:

$$\text{Gains from trade} = \text{Total transaction volume} \times \text{Average gain}.$$

Market segmentation primarily affects the average gain from trade by restricting which firms can transact. While the difference in production profits across buyers and sellers falls by about 5 percent, transaction volume actually increases slightly (Table 6, rows 3 and 4), leaving many valuable trades intact. The resulting efficiency loss arises from a lower average gain per trade rather than reduced volume.

The production requirement operates through a different channel. By forcing some permits to be harvested rather than traded, it eliminates a subset of high-value transactions altogether. The magnitude of this effect depends on how many firms are constrained in equilibrium. While the production requirement has little impact on the average value of remaining trades—buyers can typically find alternative sellers with similar profit differences—it reduces transaction volume by about 15 percent (Table 6), generating a larger overall efficiency loss than segmentation.

6.3 Cost of Redistribution via Trade Limits

The graphical analysis clarifies how trade restrictions generate foregone profits in the permit market. Table 7 translates these efficiency costs into distributional outcomes by decomposing harvest revenue into the aggregate wage bill—which accrues to workers—and residual profits and permit market returns, which accrue to boat owners. I distinguish between workers who gain from each restriction and those who lose, along with the corresponding incidence on boat owners.

Market segmentation was designed to increase production on small and medium-sized vessels (less than 15 gross tons) by placing them in a separate permit market. I find that segmentation increases their harvest share by roughly 2 percentage points, generating an aggregate earnings gain of $2.4 million for small-boat workers. These gains are offset by losses to boat owners, particularly net sellers who forgo seller surplus from trading with large boats in a unified market. Beyond small-boat owners, part of the incidence falls on large-boat labor due to reduced harvests. Large-boat owners, however, experience a slight increase in earnings, as higher equilibrium permit prices shift surplus from permit buyers to permit sellers.

The production requirement was intended to increase harvests on boats that would otherwise harvest only a small fraction of their permit allocations, thereby raising earnings for their crews. Table 7 shows that the policy increases worker earnings by about $12 million in aggregate, with corresponding losses to boat owners who can no longer sell permits profitably. As with segmentation, workers on non-targeted boats lose on average from the reallocation of harvests, while owners of those boats gain from higher permit prices that increase seller surplus at the expense of buyer surplus.

These results allow a direct comparison between the foregone profits from each trade restriction and the gains to workers. Two dimensions are relevant: increasing labor demand (job protection) and redistributing earnings toward lower-income workers. Table 8 shows that market segmentation is far more effective at increasing total labor demand. Small boats are substantially more labor intensive than the net sellers whose production increases under the production requirement, making segmentation roughly 20 times cheaper per unit of increased labor demand. Using average days at sea (77.4 per year) as a benchmark for one job-year, the implied cost of creating a fishing job through segmentation is about $77,000 annually, well within the range of estimated costs for job creation through government spending, and far below the costs associated with trade restrictions such as "buy domestic" policies.[24]

[24] Estimates from macroeconomic models of the 2009 American Recovery and Reinvestment Act suggest a cost of $136,000 per job-year (CEA 2009). Program-specific estimates range from $56,000 to $120,000

In contrast, the production requirement is more effective at redistributing earnings toward low-income workers. Figure 10 plots changes in average earnings across ventiles of the fishery income distribution. Many small-boat workers are relatively high in the fishery income distribution, limiting the targeting ability of segmentation. The production requirement instead raises earnings in the bottom half of the distribution by roughly 20 percent, compressing inequality more strongly. As a result, despite larger efficiency losses in aggregate, the production requirement is about 10 percent less costly per dollar of earnings redistributed to the lower half of the income distribution than segmentation. Nevertheless, redistribution through trade restrictions remains expensive: increasing earnings by one dollar costs roughly six dollars in foregone profits, compared to about two dollars for redistribution through the US tax system (Hendren 2020). Other regulatory instruments, such as tiered electricity pricing, achieve more modest redistribution—around 12 percent at the bottom of the distribution—with substantial deadweight loss (Borenstein 2011). It is also worth noting that even low-income fishery workers earn relatively high wages in the Icelandic context, with small-boat workers clustered around the 40th percentile of the national income distribution.

Finally, the interaction of the two policies preserves and amplifies their respective advantages. As shown in the third column of Table 9, the combined policy of market segmentation and a production requirement dominates the production requirement alone: it achieves similar redistribution toward low-income workers at comparable cost per dollar of foregone profit, while increasing labor demand much more efficiently. This outcome reflects the fact that both being a net seller and operating a small vessel target labor-intensive production, concentrating gains among the most labor-intensive and lowest-income boats. Only a regulator that values job creation but places little weight on redistribution would choose segmentation without an accompanying production requirement.

7 Conclusion

Environmental permit markets are often promoted for their ability to allocate production efficiently by shifting activity toward firms with the highest marginal value. In practice, however, these efficiency gains can conflict with distributional and employment objectives in managing environmental commons. As a result, regulators frequently restrict

(Boushey and Ettlinger 2021), while the 2018 U.S. steel and aluminum tariffs cost roughly $900,000 per job created, and "Buy American" requirements about $262,000 (Hufbauer and Jung 2020).

permit trade, both to protect specific groups and to make market-based regulation politically viable. Understanding the costs and benefits of these design choices is therefore central to environmental policy.

This paper studies the efficiency and distributional consequences of trade restrictions in Iceland's fisheries permit market, one of the world's oldest and largest. The setting features two common trading limits: a production requirement that forces firms to harvest a minimum share of their permit allocation, and segmentation of the permit market between large and small vessels. Both policies are explicitly motivated by concerns about labor demand and earnings among fishery workers. Using unique data linking detailed permit trades and production to administrative records on worker employment and earnings, I document that the introduction of permit trading reallocates production toward more productive vessels, reducing labor demand by roughly 12% and shifting earnings toward higher-income workers within the fishery. I also provide reduced-form evidence that both trading limits bind in practice, with sharp permit price differences across markets and substantial bunching at the production requirement.

To quantify the trade-offs implied by these policies, I develop and estimate a model of fishery production and permit trading that links permit choices to profits, labor demand, and earnings. The counterfactual analysis shows that the two trading limits have distinct consequences. Market segmentation substantially increases labor demand by shifting production toward more labor-intensive vessels, while imposing relatively modest efficiency losses despite large price differences across markets. The production requirement is more costly in terms of foregone profits but more tightly targeted toward low-income workers, compressing the earnings distribution more effectively. Implementing both restrictions dominates the production requirement alone, achieving greater labor demand and redistribution per dollar of foregone profit, while a regulator prioritizing job creation over income targeting might prefer segmentation on its own. Both policies are costly redistributive tools but within the range of the cost of employment programs in Western countries.

Beyond the Icelandic setting, the paper provides a general framework for evaluating distributional objectives in permit market design. The analysis highlights two key ingredients: a credible model of firm production choices under alternative market rules, and a clear mapping from those production decisions to the outcomes regulators care about. This approach can be applied in other contexts where permit markets interact with equity concerns, including pollution markets with environmental justice objectives. More broadly, evaluating market-based policies across multiple regulatory goals may help policymakers design interventions that balance efficiency with distributional considerations, and in doing so, expand the set of settings in which market-based environmental regulation is politically and socially feasible.

Citations

Agarwal, Nikhil, Charles Hodgson, and Paolo Somaini. 2020. "Choices and Outcomes in Assignment Mechanisms: The Allocation of Deceased Donor Kidneys." NBER Working Paper No. 28064.

Agnarsson, Sveinn (2007), "Krókabátar: Olnbogabörn flotans." *Vísbending*, 2, 2.

Arnason, Ragnar (2005), "Property rights in fisheries: Iceland's experience with ITQs." *Reviews in Fish Biology and Fisheries*, 15, 243–264.

Aronoff, Daniel, and Will Rafey. 2024. "Conservation priorities and environmental offsets: Markets for Florida wetlands." NBER Working Paper, No. 31495.

Aspelund, Karl, and Anna Russo. 2024. "Additionality and Asymmetric Information in Environmental Markets: Evidence from Conservation Auctions." Working Paper.

Burtraw, Dallas, and Nicholas Roy. (2023). "How Would Facility-Specific Emissions Caps Affect the California Carbon Market?" Resources for the Future, report no. 23-09.

Bushnell, James B., and Catherine Wolfram. 2012. "Enforcement of vintage differentiated regulations: The case of new source review." *Journal of Environmental Economics and Management* 64.

Borenstein, Severin. 2012. "The Redistributional Impact of Nonlinear Electricity Pricing." *American Economic Journal: Economic Policy*, 4 (3): 56–90.

Carlson, Curtis et al. (2000). "Sulfur dioxide control by electric utilities: What are the gains from trade?" *Journal of Political Economy* 108.6, pp. 1292–1326.

Colmer, Jonathan, et al. 2022. "Does Pricing Carbon Mitigate Climate Change? Firm-Level Evidence from the European Union Emissions Trading Scheme." Working Paper.

Costello, Christopher, Steven D. Gaines, and John Lynham (2008), "Can catch shares prevent fisheries collapse?" *Science*, 321, 1678–81.

De Loecker, Jan, and Chad Syverson. (2021). "An Industrial Organization Perspective on Productivity." *Handbook on Industrial Organization* (vol 4).

Dickstein, Michael J, and Eduardo Morales. (2018). "What do Exporters Know?" *Quarterly Journal of Economics*, 133(4), 1753-1801.

Ellerman, A. Denny, et al. 2000. *Markets for Clean Air: The U.S. Acid Rain Program.* Cambridge University Press.

Englander, Gabriel (2023), “Information and spillovers from targeting policy in peru’s anchoveta fishery.” *American Economic Journal: Economic Policy*, 15(4), 390-427.

Fowlie, Meredith. 2010. “Emissions Trading, Electricity Restructuring, and Investment in Pollution Abatement.” *American Economic Review*, 100 (3): 837–69.

Fowlie, Meredith, Christopher Knittel, and Catherine Wolfram. 2012. "Sacred Cars? Cost-Effective Regulation of Stationary and Nonstationary Pollution Sources." *American Economic Journal: Economic Policy*, 4 (1): 98–126.

Fowlie, Meredith, and Mar Reguant. 2022. "Mitigating Emissions Leakage in Incomplete Carbon Markets." *Journal of the Association of Environmental and Resource Economists*, 9 (2).

Garicano, Luis, Claire Lelarge, and John Van Reenen. 2016. “Firm Size Distortions and the Productivity Distribution: Evidence from France.” *American Economic Review* 11 (6).

Greenstone, Michael. 2002. “The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures.” *Journal of Political Economy* 110 (6).

Greenstone, Michael, et al. 2022. “Can Pollution Markets Work in Developing Countries? Experimental Evidence from India.” Working Paper.

Grainger, Corbett A. and Christopher Costello (2015), “Distributional effects of the transition to property rights for a common-pool resource.” *Marine Resource Economics*, 31, 1–26.

Grainger, Corbett A. and Dominic P. Parker (2013), “The political economy of fishery reform.” *Annual Review of Resource Economics*, 5, 369–86.

Greenstone, Michael, Nicholas Ryan, and Anant Sudarshan. (2022) “Can Pollution Markets Work in Developing Countries? Experimental Evidence from India.” Working Paper.

Grétarsson, Helgi Á. (2008), *Réttarsaga fiskveiða frá landnámi til 1990*. Ritröð Lagastofnunar Háskóla Íslands.

Grétarsson, Helgi Á. (2009), “Af handfæra- og strandveiðibátum: Lagaþroun 1996–2009.” *Rannsóknir í félagsvísindum*, 10, 115–53.

Hagerty, Nick. (2023). “What Holds Back Water Markets? Transaction Costs and the Gains from Trade.” Working Paper.

Hahn, Robert. 1984. “Market Power and Transferable Property Rights.” *The Quarterly Journal of Economics*, Vol. 99, No. 4.

Hahn, Robert, and Robert Stavins. 2011. "The Effect of Allowance Allocations on Cap-and-Trade System Performance." *Journal of Law and Economics*, Vol. 54, No. 4.

Hernandez-Cortes, Danae, and Kyle C. Meng. (2023). "Do environmental markets cause environmental injustice? Evidence from California's carbon market." *Journal of Public Economics*, vol. 207.

Ho, Phuong. 2023. "Why Is Trading So Important in Cap and Trade? The Roles of Economies of Scale and Productivity." Working Paper.

Hsiang, Solomon, Paulina Oliva, and Reed Walker. "The Distribution of Environmental Damages." *Review of Environmental Economics and Policy*, volume 13, issue 1.

Huang, Ling and Martin D. Smith (2014), "The dynamic efficiency costs of common-pool resource exploitation." *American Economic Review*, 104, 4071–410.

Isaksen, Elizabeth Thuestad, and Andries Richter. 2019. "Tragedy, Property Rights, and the Commons: Investigating the Causal Relationship from Institutions to Ecosystem Collapse." *Journal of the Association of Environmental and Resource Economists*, 6 (4).

Ito, Koichiro, and James Sallee. 2018. "The Economics of Attribute-Based Regulation: Theory and Evidence from Fuel Economy Standards." *Review of Economics and Statistics* 100 (2).

Jin, Di, Min-Yang Lee, and Eric Thunberg. 2019. "An Empirical Analysis of Individual Fishing Quota Market Trading." *Marine Resource Economics* 39 (4).

Keohane, Nathaniel O. 2006. "Cost savings from allowance trading in the 1990 Clean Air Act: Estimates from a choice-based model." *Moving to markets in environmental regulation: Lessons from twenty years of experience*, 19: 23.

Kroetz, Kailin, Kailin Kroetz, James Sanchirico, and Daniel K. Lew. (2015). "Efficiency Costs of Social Objectives in Tradable Permit Programs." *Journal of the Association of Environmental and Resource Economists* 2 (3), 339 - 366.

Lee, Min-Yang, and Eric Thunberg. 2013. "An inverse demand system for New England groundfish: welfare analysis of the transition to catch share management." *American Journal of Agricultural Economics* 95 (5).

Lee, Min-Yang, and Greg Ardini. 2018. "Do IFQs in the US Atlantic Sea Scallop Fishery Impact Price and Size?" *Marine Resource Economics* 33 (3).

Newell, Richard, James N. Sanchirico, and Suzi Kerr (2005), "Fishing quota markets." *Journal of Environmental Economics and Management*, 49, 437–462.

Mansur, Erin T., and Glenn Sheriff. 2021. "On the Measurement of Environmental Inequality: Ranking Emissions Distributions Generated by Different Policy Instruments."

Journal of the Association of Environmental and Resource Economists 8 (4): 721-758.

Pakes, Ariel. 1986. "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks." *Econometrica* 54 (4).

Rafey, Will. (2023). Droughts, deluges, and (river) diversions: Valuing market-based water reallocation." *American Economic Review*, Vol. 113, No. 2, pp. 430–471.

Reimer, Matthew, Josh Abbott, and A. Haynie. 2022. "Structural behavioral models for rights-based fisheries." *Resource and Energy Economics* 68.

Regnacq, Charles, Ariel Dinar, and Ellen Hanak. 2016. "The Gravity of Water: Water Trade Frictions in California." *American Journal of Agricultural Economics*, vol. 98, issue 5.

Robertson, Molly, Eunice Ko, Eddie Bautista, Alan Krupnick, and Wesley Look. "Prioritizing Justice in New York's Cap-Trade-and-Invest: Obligating Electricity and Capping Generator Emissions." Resources for the Future Report 24-05.

Ryan, Nicholas, and Anant Sudarshan. "Rationing the Commons." *Journal of Political Economy* 130 (1): 210-257.

Shapiro, Joseph, and Reed Walker. 2021. "Is Air Pollution Regulation Too Lenient? Evidence from US Offset Markets." NBER Working Paper No. 28199.

Sigurdsson, Josef. (2024). "Labor Supply Responses and Adjustment Frictions: A Tax-Free Year in Iceland." Working Paper.

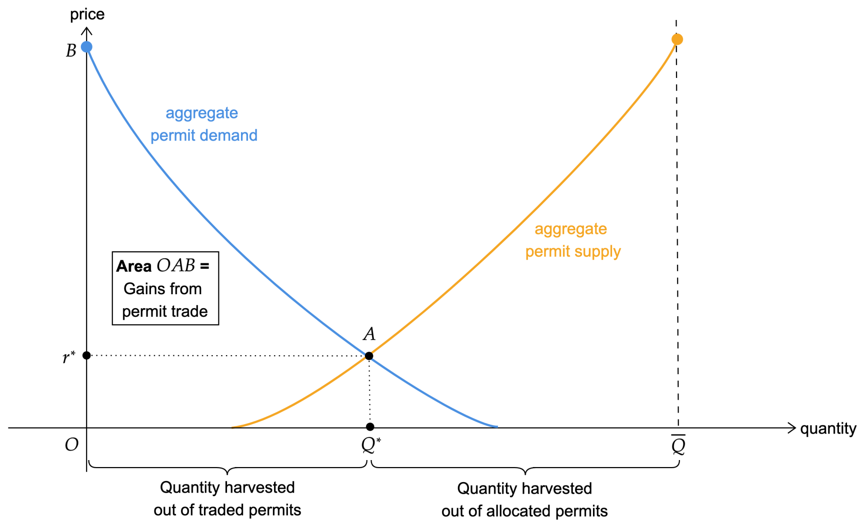
Smith, Martin D. (2012), "The new fisheries economics: Incentives across many margins." *Annual Review of Resource Economics*, 4, 379–429.

Toyoma, Yuta. (2024). "Dynamic Incentives and Permit Market Equilibrium in Cap-and-Trade Regulation." *American Economic Journal: Microeconomics*, Volume 16, no. 3, 374–423.

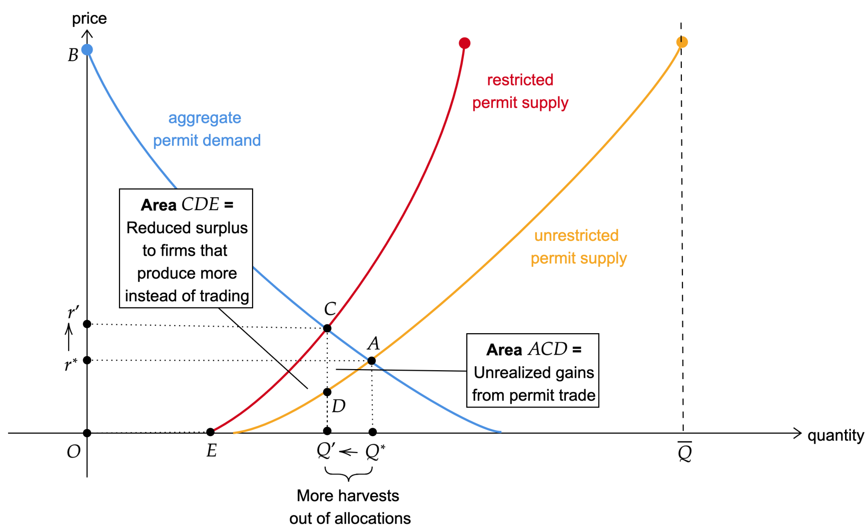
Walker, Reed. (2013). "The Transitional Costs of Sectoral Reallocation: Evidence From the Clean Air Act and the Workforce." *Quarterly Journal of Economics*, 128 (4): 1787-1835.

Tables and Figures

Figure 1. Graphical analysis of a permit market and a production requirement



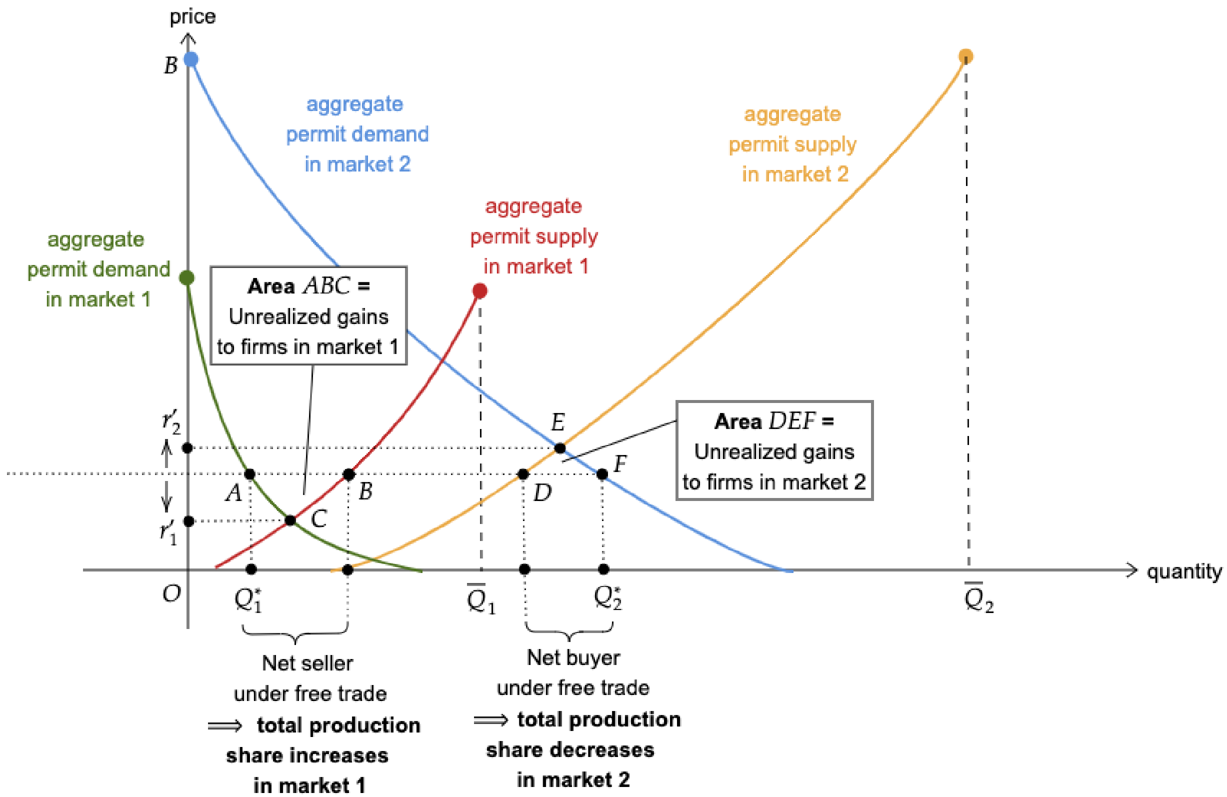
(a) Gains from permit trade



(b) Production requirement

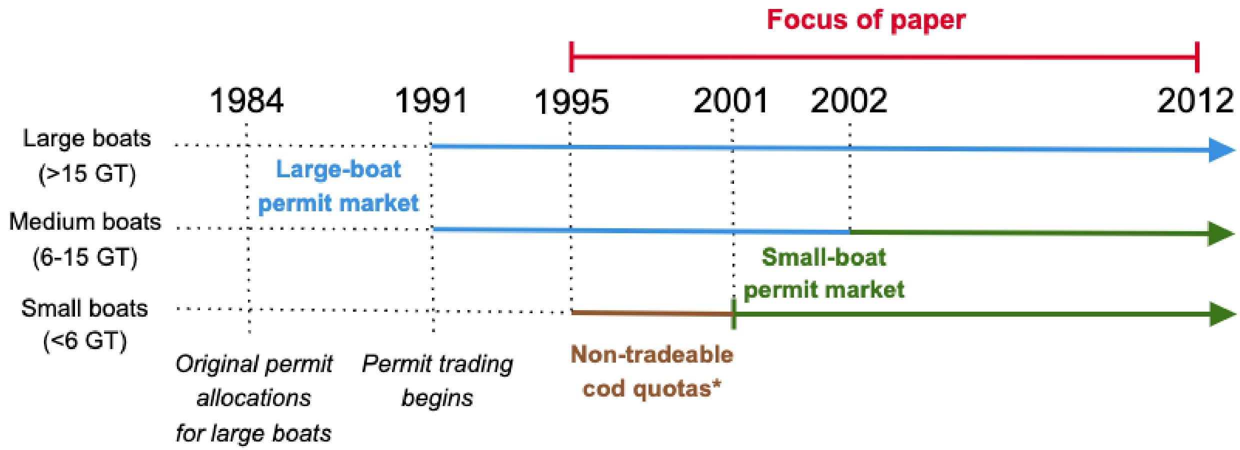
Note: The figure describes the lost gains from trade from two common types of trading limits in a permit market: requirements to produce a minimum amount from permit allocations and segmenting a market. It does so under a competitive market equilibrium in a permit market for a generic initial permit allocation. It outlines aggregate permit demand and aggregate permit supply curves, which depend both on market participants' permit choices—which are themselves functions of production profits—and the initial allocations to each participant. Sub-figure (a) shows the basic equilibrium and the gains from trade. Sub-figure (b) shows the supply shift that occurs when there is a production requirement that binds firms with low production.

Figure 2. Graphical analysis of segmentation



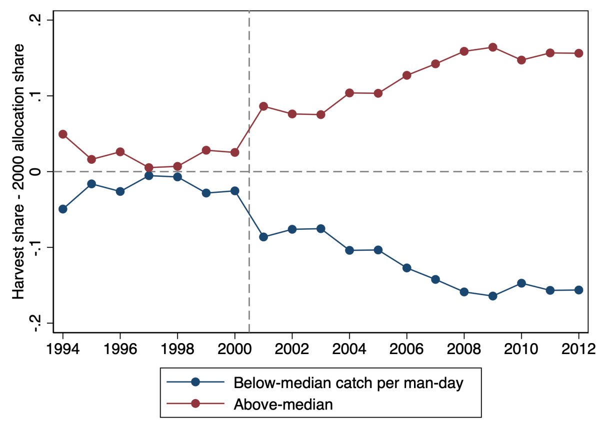
Note: The figure describes the lost gains from trade from segmenting a permit market. It does so under a competitive market equilibrium in a permit market for a generic initial permit allocation. It outlines aggregate permit demand and aggregate permit supply curves, which I define in the text as the relationship between excess permits or excess production and permit prices. The foregone profits are the two triangles. Segmentation is designed to increase production in the market with the more generous cap, i.e. the one with a lower equilibrium permit price. This increases production profits but at the expense of returns in the permit market.

Figure 3. Timeline of fishery regulation in Iceland

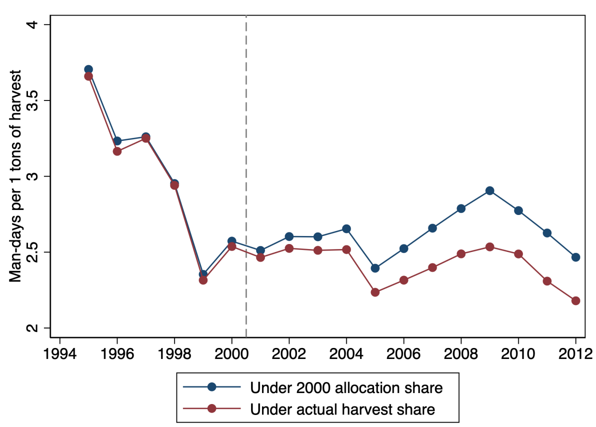


Note: The figure shows some key years in Icelandic fisheries management that are relevant to this paper. There is an asterisk on the non-tradeable cod quotas because about 250 small boats were also under day restrictions after 1995; many of these day boats operated mostly seasonally and represent less than 2% of aggregate revenue, so they are not a focus of this paper. They were also placed into the permit market in 2004, though many later transitioned to a summer coastal fishing program in 2008.

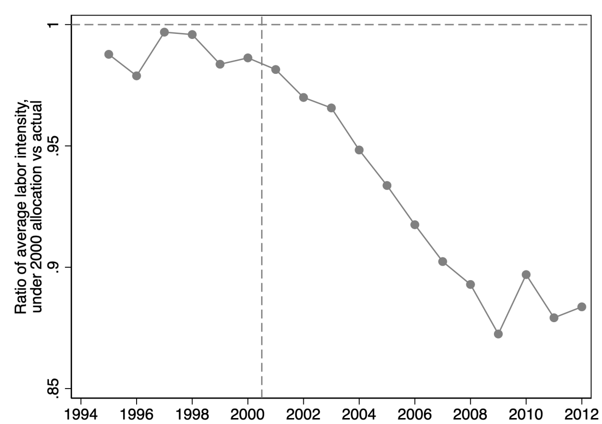
Figure 4. Impact of permit market trade on harvests and labor intensity



(a) Reallocation of harvest among small boats



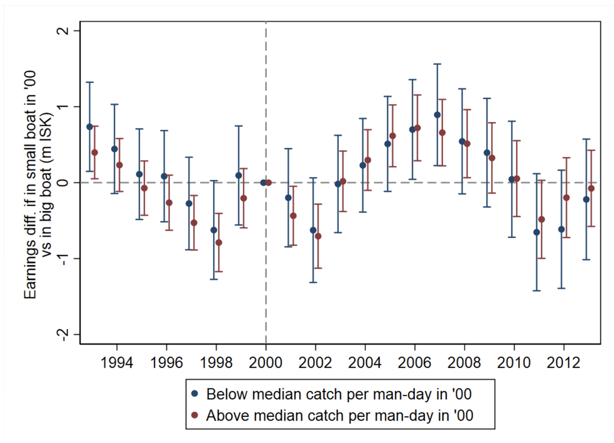
(b) Labor intensity (harvests per person-day), actual vs. if allocation harvested



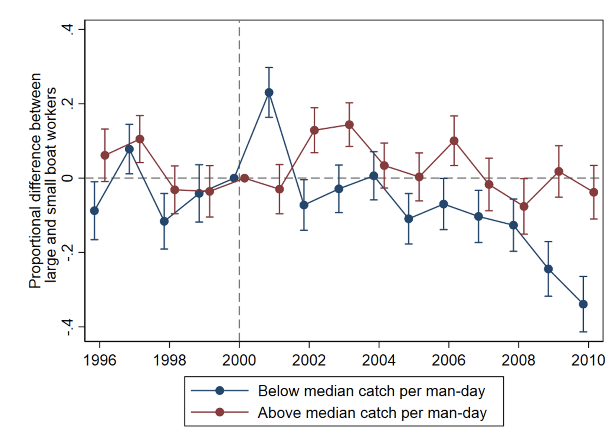
(c) Relative difference of labor intensity, actual vs. if allocation harvested

Note: The figure shows key changes in production after permit trading is introduced for small boats. Sub-figure (a) shows the differences in harvest share, relative to the allocation share, among small and medium boats after permit trading is introduced, split at the median catch per man-day (a measure of productivity). Sub-figure (b) shows how this impacted the average labor intensity of production. It compares the average labor intensity (man-days per ton of harvest, i.e. the inverse of the productivity measure used in sub-figure a) in red to the implied average when the boats are weighted by their 2000 allocation share. It shows how how much of the change in labor intensity can be attributed to the shift in harvest due to permit trade. Sub-figure (c) takes the ratio of the two measures in sub-figure b to show that the observed labor intensity is about 88% lower than what would be observed if the same boats had kept their harvest shares at their 2000 allocation share. Permit trading has made fisheries production less labor-intensive.

Figure 5. Impact of permit market trade on worker income



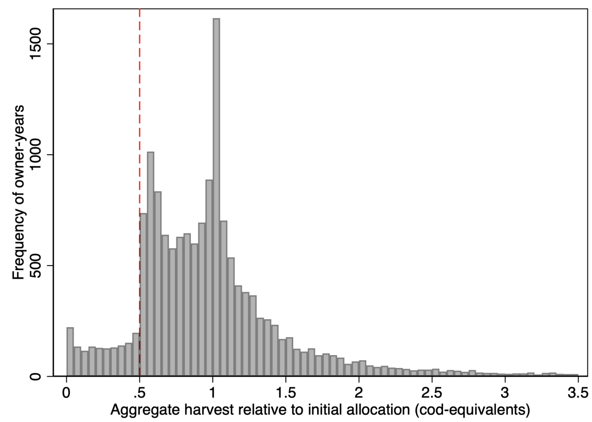
(a) Average earnings difference in panel of workers in small boats vs big boats in 2000



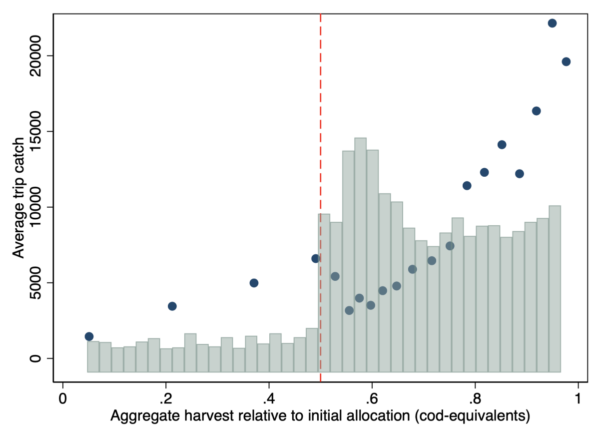
(b) Average earnings difference between workers in small boats vs big boats every year

Note: The figure shows key changes worker outcomes on the introduction of permit trading in Icelandic fisheries. Sub-figure (a) shows the average earnings difference among workers in small boats in 2000 only, split along median harvest per person-day, relative to large-boat workers in 2000. This traces their earnings whether they are in the fishery or not. Sub-figure (b) shows the average earnings difference among workers each year relative to large-boat workers, i.e. it conditions on being in the fishery every year. It shows that across most years, average earnings fall on less-productive boats. These workers tend to be low-income already. Permit trading transfers income from lower- to higher-income workers.

Figure 6. production requirement's impact



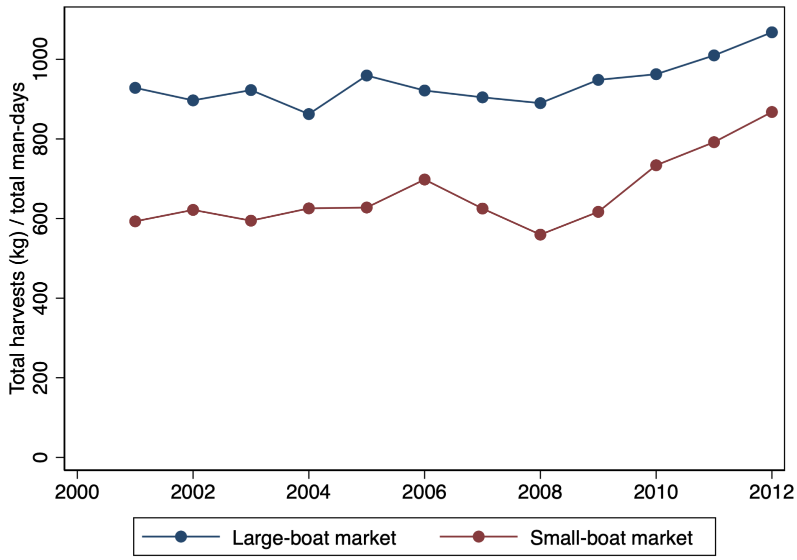
(a) Permit holdings relative to allocation: bunching at 50%



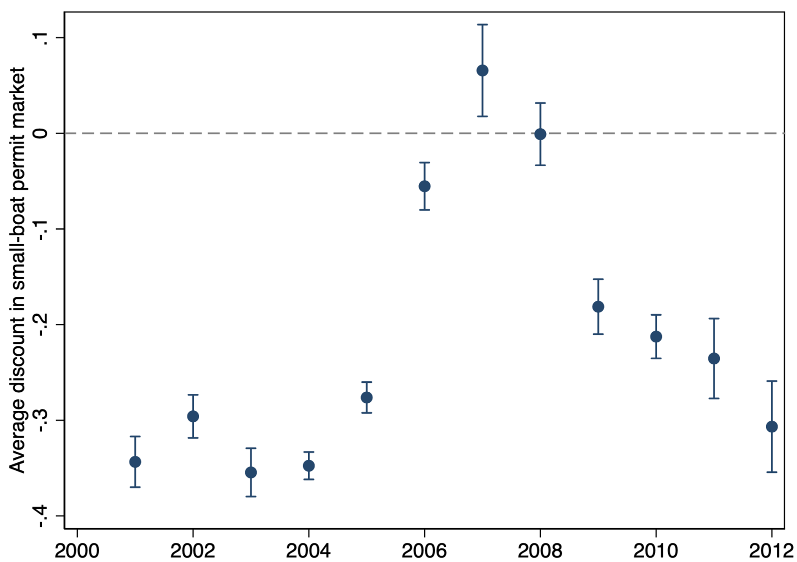
(b) Binned scatter-plot: average trip less productive above cutoff

Note: The figure shows that the production requirement binds: there is considerable bunching at 50% of the permit allocations. About 8% of firm-years are below 50%, most of whom exit in the following year. Sub-figure (b) zooms in to show that bunching firms have lower average daily harvests, going out on more days to get to the 50% mark.

Figure 7. Segmented market's impact



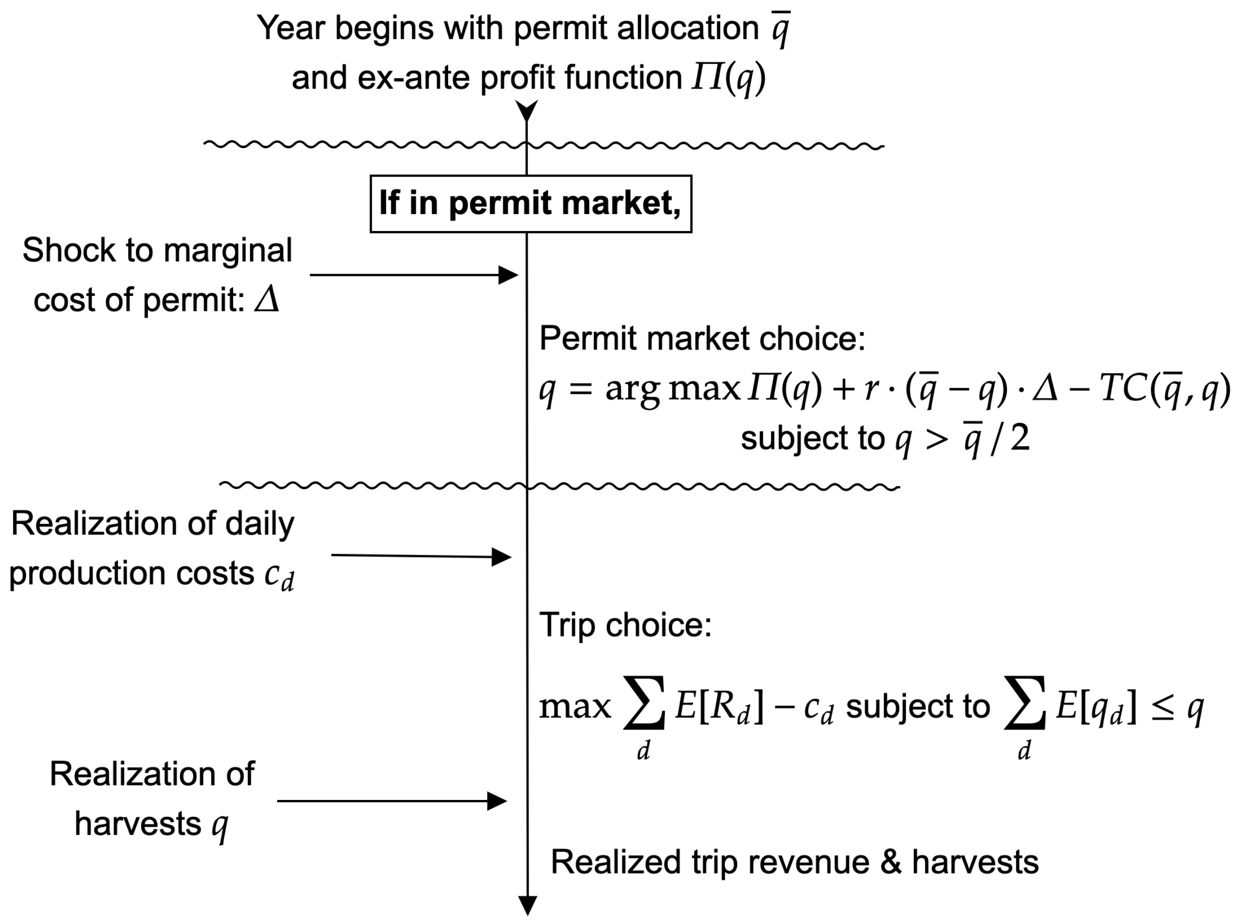
(a) Small-boat production is more labor-intensive



(b) Permits are on average cheaper in most years

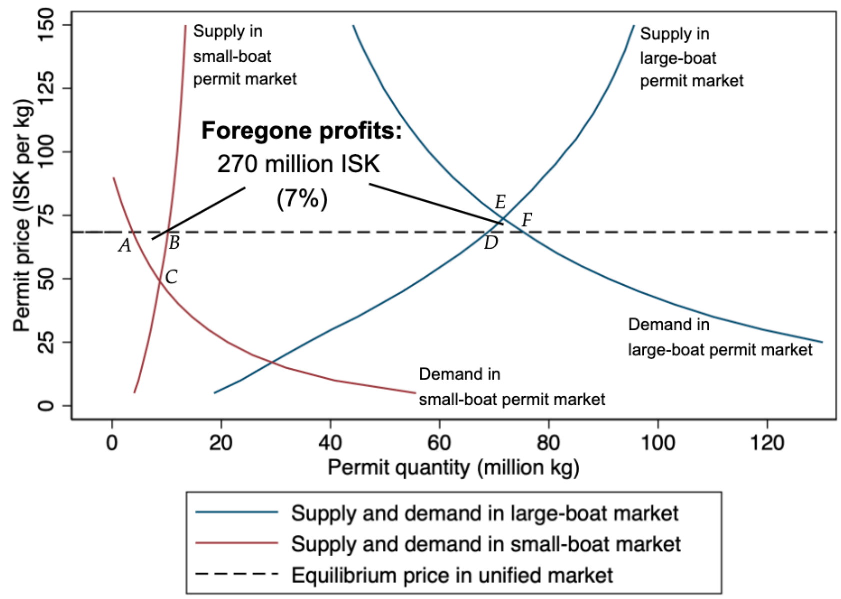
Note: The figure shows the impact of the small-boat market. First, sub-figure (a) highlights that small-boat production is more labor-intensive, i.e. lower harvests per person-day, than large-boat production. Sub-figure (b), meanwhile, highlights a sufficient statistic for efficiency differences due to segmentation: differences in the permit price, the effective shadow marginal cost of production. Regressing permit prices from all trades with species-year fixed effects, the coefficient reports the average percentage difference in permit transaction price in the small and large boat market. In most years, it is considerably lower, reflecting more generous caps to the small-boat market.

Figure 8. Timing of decisions, shocks in model

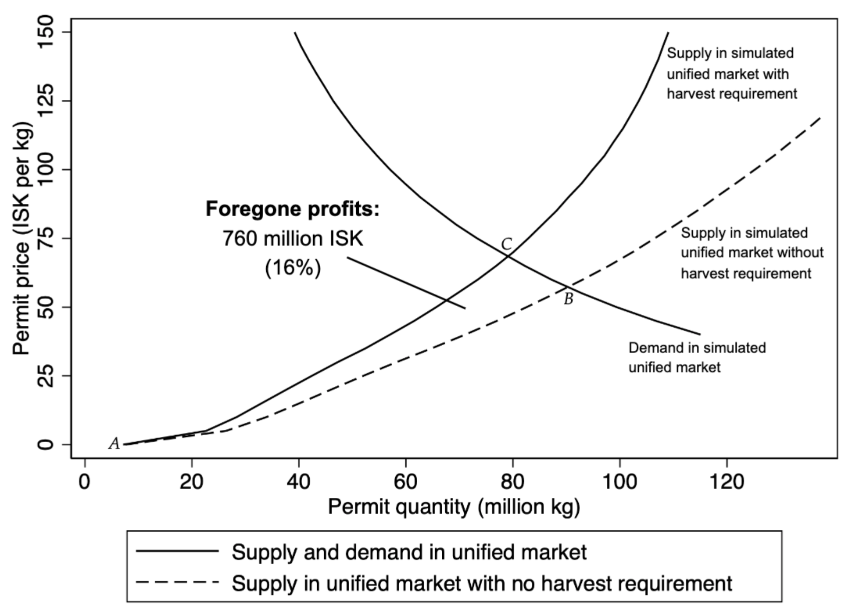


Note: The figure the timing of shocks and decisions in the model. For boats in the non-tradeable cod system, days are chosen based on permit allocation only; there is no permit choice. Boats are assumed to trade permits once, before cost shocks are realized, and therefore based on the ex-ante profit function. All quantities are in cod-equivalent units, the units at which the trade limit binds.

Figure 9. Graphical analysis: permit demand and supply in 2003



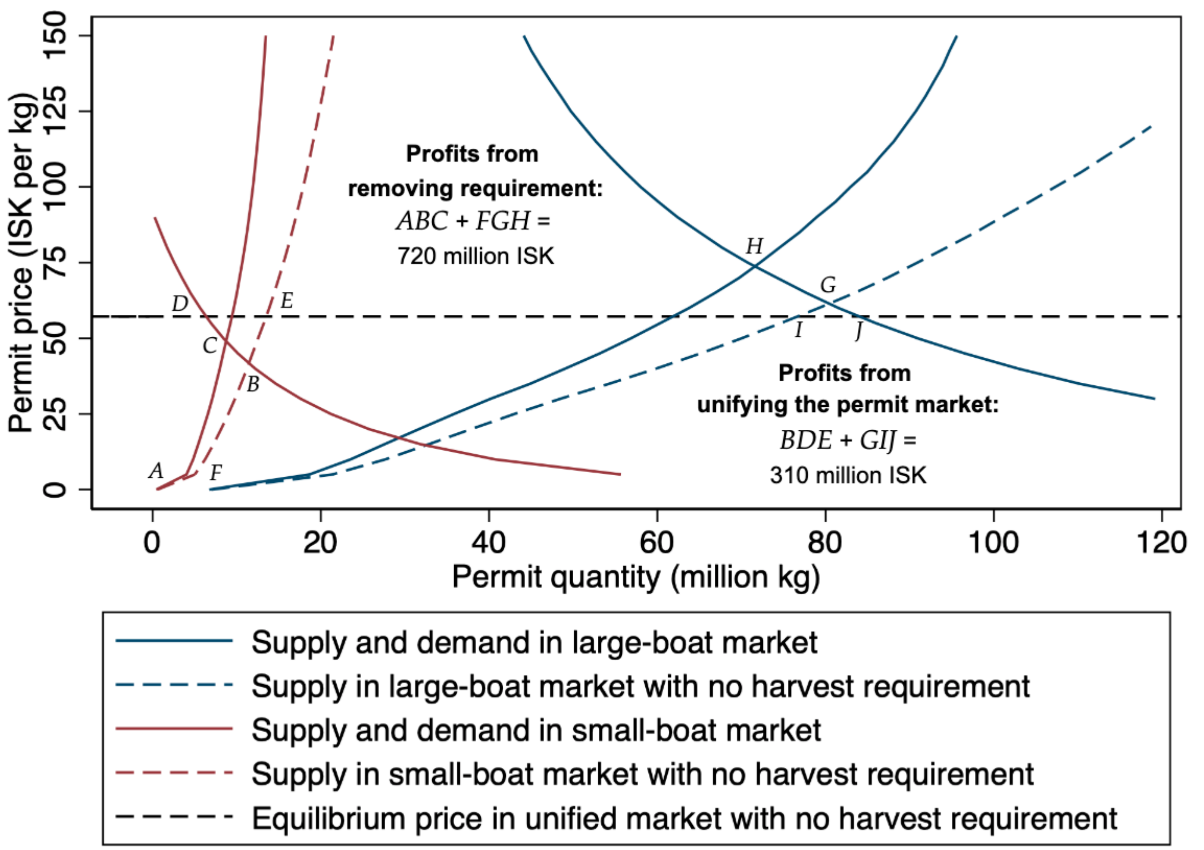
(a) Impact of segmentation



(b) Removing harvest restriction in a unified market

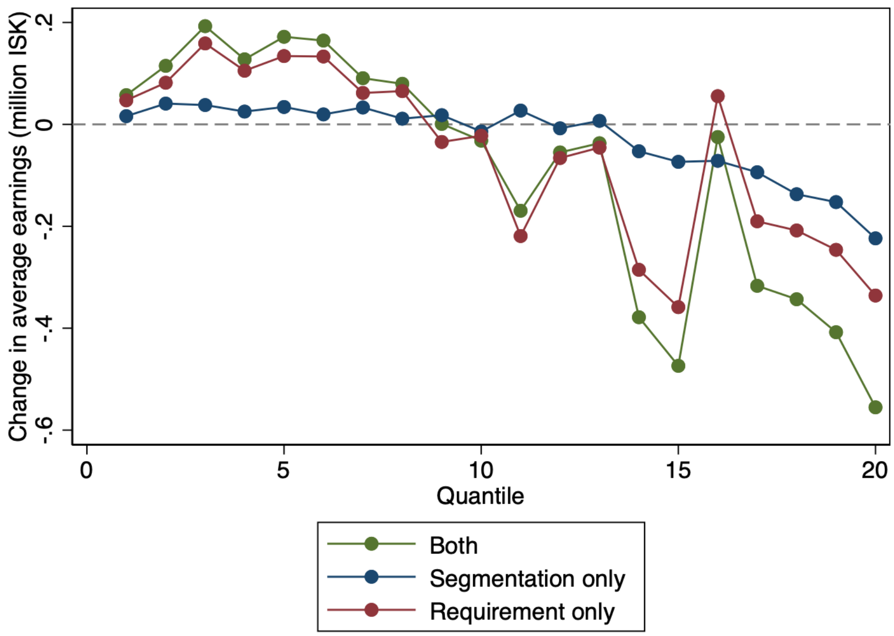
Note: These figures show the aggregate permit supply and demand curves for the actual permit market in 2003 in sub-figure (a) and a simulated unified market in sub-figure (b) with and without the production requirement. The unified equilibrium permit price reported in (a) is the intersection of the solid lines in (b). It then highlights the foregone profits in each.

Figure 10. Profits from removing both trading limits



Note: This figure shows the impact of removing the two trading limits from the permit market in 2003. It begins with the supply and demand in the segmented markets and then removes the production requirement to generate more permit supply. Then it highlights the remaining profit gains from unifying the market without the production requirement.

Figure 11. Trade-off of Trade Limits: Foregone profits vs. outcomes for targeted group



Note: The figure shows changes in earnings across the fishery worker income distribution. It plots changes in average earnings by ventile of the fishery worker income distribution, pooling across all years, for three market designs relative to the market with no trading limits: segmenting the market by boat size only (blue), introducing the production requirement only (red), and the actual design that implemented both (green).

Table 1. Summary Statistics

	1997	2002	2010
Panel A: Fishing Boats			
No. boats	906	884	636
No. firms	958	947	648
Total harvests (thousand cod-equivalent tons)	293	304	278
Total revenue (all species, billion ISK)	24.5	37.9	70.8
Total trips (million)	4.60	4.09	2.88
Fraction trawlers	0.135	0.103	0.106
Fraction small (< 6 gross tons)	0.432	0.376	0.356
Fraction medium ($6 - 15$ gross tons)	0.282	0.342	0.389
Fraction large (> 15 gross tons)	0.286	0.282	0.253
Harvest share to trawlers	0.576	0.589	0.553
Harvest share to small boats	0.087	0.060	0.018
Harvest share to medium boats	0.081	0.109	0.161
Panel B: Fisheries Labor			
No. workers	8771	7505	6051
No. workers, small boats	1100	1270	722
In capital city region	0.273	0.249	0.243
Average earnings (million '20 ISK)	7.39	8.99	10.2
Fraction male	0.962	0.960	0.950
Average age	35.1	37.3	39.5
Fraction UI	0.100	0.117	0.162
Fraction foreign-born	0.017	0.031	0.065
Fraction university degree	0.024	0.025	0.051
Average fraction earnings in fishing	0.796	0.814	0.814
Fraction with $> 90\%$ fish earnings, small boats	0.568	0.580	0.570
Fraction with $> 90\%$ fish earnings, large boats	0.642	0.659	0.705
Fraction moving next year	0.221	0.108	0.080
Fraction in fishery next year	0.766	0.791	0.822
Panel C: Comparison Sample of Non-Fisheries Workers (16-70)			
In capital city region	0.645	0.661	0.672
Fraction male	0.422	0.427	0.418
Average age	39.2	41.0	46.6
Average earnings (million ISK)	3.53	4.69	5.00
Fraction foreign-born	0.036	0.027	0.026
Fraction university degree	0.187	0.232	0.357

Note: Harvests are measured in cod-equivalents; see Appendix Section A. All monetary values are inflated using the consumer price index for Iceland in January 1, 2020. At that time, the market exchange rate was 122.4 ISK to 1 USD, i.e. 1 million ISK $\approx$ 8,170 USD. Panel C is information from a random sample of 10% of individuals who were never flagged as working in the fisheries through all the tax and pay-slip data. Boats with day restrictions are not included.

Table 2. Event-Study Estimates from Permit Market Expansion

	Overall income (1)	Fish income (2)	Not working (3)	In fisheries (4)	Frac. fishing income (5)	Moved (6)
Panel A: panel of workers in fisheries in 2000						
Pre-2000 $\times\mathbf{1}$(Small boat in ’00)	-0.107	-0.139	0.093	-0.166	-0.084	0.061
	(0.127)	(0.137)	(0.005)	(0.006)	(0.012)	(0.006)
Post-2000 $\times\mathbf{1}$(Small boat in ’00)	0.094	0.314	0.041	-0.057	-0.001	0.033
	(0.127)	(0.138)	(0.004)	(0.006)	(0.012)	(0.005)
Panel B: panel of workers in fisheries in 2000, split by ’00 median daily catch						
Post-2000 $\times\mathbf{1}$(Below ’00 median)	0.030	0.243	0.0422	-0.077	-0.012	0.013
	(0.174)	(0.184)	(0.006)	(0.008)	(0.016)	(0.006)
Post-2000 $\times\mathbf{1}$(Above ’00 median)	0.158	0.383	0.040	-0.037	0.010	0.052
	(0.165)	(0.179)	(0.005)	(0.007)	(0.016)	(0.006)
Birth decade FE	X	X	X	X	X	X
No. workers	7,532	7,532	7,532	7,532	7,532	7,532
No. small-boat workers	1,210	1,210	1,210	1,210	1,210	1,210
’00 Mean: small boats	5.16	3.93	0.00	1.00	0.705	NA
’00 Mean: large boats	7.96	6.85	0.00	1.00	0.772	NA
Panel C: cross-section of fishery workers each year						
Pre-2000 $\times\mathbf{1}$(Small boat)	0.476	0.402			-0.016	
	(0.128)	(0.138)			(0.012)	
Post-2000 $\times\mathbf{1}$(Small boat)	-1.03	-0.991			-0.016	
	(0.127)	(0.136)			(0.011)	
Panel D: cross-section of fishery workers each year, split by ’00 median daily catch						
Post-2000 $\times\mathbf{1}$(Below ’00 median)	-1.45	-1.43			-0.029	
	(0.172)	(0.182)			(0.015)	
Post-2000 $\times\mathbf{1}$(Above ’00 median)	-0.534	-0.464			-0.001	
	(0.166)	(0.180)			(0.015)	
Birth decade FE	X	X			X	
No. worker-years	161,316	161,316			161,316	
No. small-boat worker-years	18,135	18,135			18,135	

Note: The table shows results from a simple differeince-in-differences of small- and large-boat workers across years, pooling 1993-1999 and 2001-2012 for the pre- and post-years respectively. Panel A is a cross-section of fishing workers each year, highlighting earnings differences within each year. Panel B follows the panel of workers who were in fishing boats in 2000. All specifications include fixed effects for birth decade. Income is measured in million ISK. All monetary values are inflated using the consumer price index for Iceland in January 1, 2020. At that time, the market exchange rate was 122.4 ISK to 1 USD, i.e. 1 million ISK $\approx$ 8,170 USD. “Moved” is an indicator for filing tax returns in a different postal code than in 2000.

Table 3. Statistics by Productivity of Boats

	Below-median treated boat	Above-median treated boat	Control boat
Avg. fishery income, 2000	$31,900	$46,909	$55,775
Avg. fishery income percentile, 2000	37	47	53
Avg. income percentile, Iceland in 2000	59	71	75
Wage bill / revenue in 2000	0.31	0.30	0.21
Average share of income from fishing, 2000	0.71	0.76	0.79
Average share of income from fishing, 2007	0.75	0.72	0.79
Frac. in capital region, 2000	0.20	0.14	0.28
Frac. in capital region, 2007	0.22	0.07	0.25
Frac. foreign, 2000	0.08	0.01	0.02
Frac. foreign, 2007	0.21	0.18	0.07
Avg. age, 2000	36.9	37.9	36.2
Avg. age, 2007	39.0	37.2	37.7

Note: The table shows some key summary statistics by the three groups tracked in the reduced-form analysis. The first two columns show statistics for he treated boats in 2000 (small and medium boats that are put into a permit market) split at the median catch per man-day, a measure of productivity. It tracks some income measures and a measure of labor share (the share of harvest revenue running to the wage bill) in 2000, the year before small boats are placed in the permit market. It also tracks a series of demographic characteristics in 2000 and 2007 (many years after permit trading) to show that the demographics of fishery workers changed starkly, particularly on small boats.

Table 4. Parameters of interest

Description	Symbol	
Production		
Expected daily revenue	R_{id}	regression of realized daily revenue on observed characteristics
Daily cost	c_d	$c_{id} \sim$ Log normal(μ_c, σ_c), where each parameter is a function of size and gear mix.
Mean daily cost	μ_c	from aggregate choice of days to meet quantity goal
Variation of daily costs	σ_c	from likelihood of choosing particular day given its revenue and the quantity goal
Permit market		
Shock to marginal cost	Δ_i	$\Delta_i \sim$ Log normal$(\mu_\Delta, \sigma_\Delta)$, from variation in wedge Π'/r for similar boats and allocations
Transaction costs: base cost	α	allows for increased marginal cost as permit choice grows from allocation $\bar{q}$.
difference when selling	β	how relationship between wedge and allocation differs under selling vs buying permits
curvature	η	sensitivity of relationship between wedge and allocation to magnitude of trade.

Note: The table shows the key parameters of interest in the model. The production parameters determine each boat's harvest profit function. The market parameters allow for transaction costs that increase as producers choose permits away from their allocation.

Table 5. Structural estimates for three years

	1999		2001		2003	
Panel A: Average cost per unit and average unit revenue (ISK per kg) across boats						
	Cost per kg	Revenue per kg	Cost per kg	Revenue per kg	Cost per kg	Revenue per kg
Overall	13.7	109.7	20.2	136.1	16.3	133.6
Handline	11.4	108.5	22.0	131.1	12.4	133.2
Hand-longline	15.5	107.5	23.9	127.2	22.3	126.4
Net-hand-longline	12.9	115.0	7.08	147.7	30.0	143.5
Longline	22.1	107.3	21.5	129.3	14.1	129.2
Gillnet	3.57	121.0	22.3	161.7	26.0	154.0
Seiner	12.6	155.5	13.5	144.3	16.5	140.2
Trawler	18.0	97.3	17.3	118.6	9.4	120.9
Small boat	16.3	109.6	22.3	131.1	14.3	132.4
Medium boat	11.6	112.6	19.7	139.8	19.7	136.1
Large boat	12.5	106.9	17.9	138.3	15.6	132.7
Panel B: Market parameters						
$E[\Delta]$	0.995		1.17		1.82	
$Var(\Delta)$	0.048		0.050		0.104	
$\hat{\alpha}$	-0.280		-0.085		-2.47	
$\hat{\beta}$	-62.3		-50.4		-47.5	
$\hat{\eta}$	-1.80		-1.77		-0.91	

Note: Panel A shows the average unit cost and average unit revenue for different boat types, i.e. average total costs per kg quantity for each boat. Panel B shows estimates of the residual variation in the wedge between marginal profits and permit price Δ as well as the parameters of the transaction cost function. See Table 4 for details. All monetary values are inflated using the consumer price index for Iceland in January 1, 2020. At that time, the market exchange rate was 122.4 ISK to 1 USD, i.e. 1 million ISK $\approx$ 8,170 USD. The full set of cost and marekt parameters can be found in Appendix Section C.

Table 6. Regression of wage bill

	(1)	(2)
Revenue	0.162	0.186
	(0.053)	(0.055)
Revenue × log(boat size)	0.017	0.007
	(0.002)	(0.002)
Revenue × indicator for...		
Hand-longliner	-0.085	-0.022
	(0.076)	(0.077)
Handliner	-0.157	0.224
	(0.281)	(0.403)
Longliner	0.036	0.049
	(0.053)	(0.054)
Other	0.066	0.091
	(0.056)	(0.056)
Seiner	-0.118	0.060
	(0.053)	(0.054)
Trawler	0.121	0.094
	(0.053)	(0.054)
Year fixed effects	X	X
Firm fixed effects		X
R^2	0.8883	0.9083
N	14,893	14,293

Note: This table shows the results of a regression of fishery firm's total wage bill on the firm's annual harvest revenue. It interacts the coefficient on revenue with the (log) boat size and the gear mix. When a firm has multiple boats, I pick the size and gear mix of the smallest boat. The first column reports results for a specification with no firm fixed effects; the second column reports results with firm fixed effects, showing how the wage bill changes as revenue changes across years.

Table 7. Decomposing the Gains from Trade

	Gains from trade (million USD)	Total transaction volume (million kg)	Average gain (USD per kg)
Both	103.5	529.8	0.20
Requirement	109.4	515.3	0.21
Segment	121.7	608.5	0.20
No limits	127.8	606.5	0.21

Note: The table shows the gains from trade under four permit market designs, pooling years from 2001 onward. It compares the efficient benchmark ("no limits") to including market segmentation, imposing the production requirement, and the actual design that implements both trading limits. It then shows the gains from trade: the difference in total profits under the permit market versus all boats harvesting their permit allocation. This is decomposed into the total trade volume and the average gain per trade. It shows that segmentation impacts the average gain from trade, while the requirement impacts the total transaction volume. The requirement has a larger efficiency impact because it constrains more production relative to the efficient benchmark.

Table 8. Comparing the Two Trade Limits: Which Workers Gain?

	Gain (million USD)	Lose (million USD)
Segmentation		
Which workers?	Small-boat	Large-boat
Total transfer to workers	2.4	-4.7
Total transfer to their owners	-3.6	2.7
production requirement		
Which workers?	High sellers	Everyone else
Total transfer to workers	12	-17
Total transfer to their owners	-28	15

Note: The table summarizes which workers and boat owners gain from the implementation of trade limits in Iceland's fisheries permit market. It compares total earnings to different groups of workers and firms when each trading limit is implemented, relative to a counterfactual market without trade limits. It emphasizes how each limit targets different workers: small-boat labor in the case of segmentation and labor on high-selling boats in the case of the production requirement. It also emphasizes that owners of non-targeted boats gain on average through changes in the permit price, namely because permit prices increase and this transfers surplus from buyers to sellers.

Table 9. Comparing the Two Trade Limits: Redistribution and Increase in Labor Demand

	Segment	**Harvest requirement**	**Both**
Income change, workers < median income (million USD)	0.90	2.98	3.95
Profit change, owners < median profits (million USD)	-1.90	4.85	3.62
Increase in labor demand (thousand person-days)	6.21	0.98	8.22
Cost (foregone gains from trade) (million USD)	6.17	18.5	24.3
Cost per $1 increase to low-income labor	6.82	6.19	6.15
Cost per 1,000 person-day increase in labor demand	0.99	18.9	2.9

Note: The table shows how each trade limit impacts both total labor demand and the distribution of income in Iceland's fisheries. It shows how four key economic outcomes change relative to a permit market with no trade limits: total income to the lower half of the fishery worker income distribution, total profits to the lower half of the boat owner profit distribution, the total labor demand in person-days, and the profits (i.e. the change in gains from trade). It then divides the change in profits by the change in earnings to low-income workers to get the cost of redistribution via each limit. It compares three market counterfactuals: segmenting the market only, only implementing the production requirement, and the actual design that implemented both limits. Segmentation mainly increases labor supply, while the production requirement is the better redistributive policy. Implementing both limits increases labor demand and promotes redistribution, while also shifting the incidence of the trade limits onto the owner of higher-profit boats.

Appendix

A Details on Framework

A.1 Implementing the profit-maximizing allocation

The profit-maximizing allocation assigns production to firms to maximize aggregate surplus, as if one agent controls all firms' production choices:

$$\max_{q_i} \sum_i \Pi(q_i, \mathbf{z}_i) \text{ subject to } \sum_i q_i \leq \bar{Q} \tag{42}$$

Under the solution, all firms equalize marginal profits to the marginal shadow cost λ:

$$\frac{\partial}{\partial q_i} \Pi(q_i, \mathbf{z}_i) = \lambda, \quad \forall i \tag{43}$$

where the marginal shadow cost λ is the Lagrange multiplier from the aggregate production cap.

Implementing the profit-maximizing allocation with a permit market. The seminal result underpinning environmental permit markets is that this profit-maximizing allocation is implementable by allocating permits to produce and allowing those permits to be traded in a market in competitive equilibrium (Crocker 1966; Dale 1968; Montgomery 1972). Let $\bar{q}_i$ be the allocation to firm i, such that $\sum_i \bar{q}_i = \bar{Q}$.

Assumption 1. *Firms take permit prices as given.*

Assumption 2. *There are no search or hassle costs in the permit market, such that the marginal cost of a permit is summarized by the permit price.*

Assumption 3. *Firms harvest all permit holdings q_i. They choose the permits to hold to maximize total profits, given the production profit function and permit allocation $\bar{q}_i$.*[25]

The final component of the competitive equilibrium determines the equilibrium permit price:

[25] In this simple setting, choosing permits or choosing production is equivalent. When production is uncertain or there are other provisions like banking, this is no longer the case.

Assumption 4. *The permit market clears such that aggregate permit choice is equal to the total number of permits available:*

$$\sum_i q(r, \mathbf{z}_i) = \sum_i \bar{q}_i = \bar{Q} \tag{44}$$

Under the optimization problem in (1) and market-clearing in (44), the market equilibrium implements the profit-maximizing allocation, i.e. a traditional First Welfare Theorem argument.[26] The permit price will be equal to the shadow marginal cost of production characterized in (43).

A.2 Details of day selection process

The selection process is as follows:

1. Define daily profits of boat i on day t as

$$\pi_{it} = E[R_{it}|\mathcal{I}_i] - c_{it} \tag{45}$$

2. Denote the ordered set of **positive** daily profits by $\{\pi_{i(k)}\}$, where

$$\pi_{i(1)} \geq \pi_{i(2)} \geq \cdots \geq \pi_{i(n)} \text{ and } \pi_{i(k)} \geq 0, \forall k$$

   Here, $k = 1, 2, \ldots, n$ indexes the ordered days, and $t_{(k)}$ is the original day corresponding to the k-th highest profit, i.e., $\pi_{i(k)} = \pi_{it_{(k)}}$.

3. Denote the corresponding expected harvests denoted by $\{q_{i(k)}\}$, where

$$q_{i(k)} = E[q_{it_{(k)}}|\mathcal{I}_i]$$

4. Let $\mathcal{S}(q_i, \mathcal{I}_i, c_i)$ be the set of days of highest profit until harvests equal permit holdings:

$$\mathcal{S}(q_i, \mathcal{I}_i, c_i) = \{t_{(1)}, \ldots, t_{(k)} \mid \sum_{m=1}^{k} E[q_{i(m)}|\mathcal{I}_i] \leq q_i\} \tag{46}$$

   which depends on c_i through the arrangement of days $t_{(k)}$.

[26] A set of theoretical work has confirmed how market power or transaction costs change the ability of the permit market to implement the profit-maximizing allocation (Hahn 1984; Stavins 1995).

5. Then the **day choice vector** $\mathbf{d}_i$ indicates which days are in $\mathcal{S}(q_i, \mathcal{I}_i, c_i)$:

$$\mathbf{d}_i = \{d_{it}\}_{t=1,\ldots,T}, \text{ where} \tag{47}$$

$$d_{it} = \begin{cases} 1 & \text{if } t \in \mathcal{S}(q_i, \mathcal{I}_i, c_i) \\ 0 & \text{if } t \notin \mathcal{S}(q_i, \mathcal{I}_i, c_i) \end{cases} \tag{48}$$

6. The total number of days is

$$D(q_i, \mathcal{I}_i, c_i) = \sum_t d_{it} \tag{49}$$

A.3 Identifying revenue and quantity expectations

First, I assume that I perfectly specify the boat's information set at the time of day choice when forming quantity and revenue expectations:

Assumption 5. *Boats form expectations over daily revenue R_{it} and daily harvests q_{it} as a function of boat characteristics $\mathbf{z}_i$ and day characteristics $\mathbf{z}_t$. Therefore the set of chosen days depends on these characteristics: $\mathcal{S}(q_i, \mathcal{I}_i, c_i) = \mathcal{S}(q_i, \mathbf{z}_i, \mathbf{z}_t, c_i)$*

Any deviation between observed realized revenue and the expected revenue is the forecast error of a boat:[27]

Definition. *The **forecast error** of a boat i for day t is observed as*

$$\xi^R_{it} = R_{it} - E[R_{it}|\mathbf{z}_i, \mathbf{z}_t] \tag{50}$$

$$\xi^q_{it} = q_{it} - E[q_{it}|\mathbf{z}_i, \mathbf{z}_t] \tag{51}$$

such that I change the notation of the set of days of highest profits up until q_i so that it depends on these forecast errors: $\mathcal{S}(q_i, \mathbf{z}_i, \mathbf{z}_t, c_i, \xi^R_i, \xi^q_i)$.

Forecast errors are considerable in fisheries, since there is great uncertainty in the location and quantity of fisheries in different locations at particular times. Plugging into the inequalities above shows that beliefs over both quantities and revenues play a role in day

[27] This error term would also include measurement error in revenue. I observe fish prices as averages of species-size-gear mix-region-month bins, in both fish auctions and from contracts for vertically integrated boats, not the boat-specific prices directly. The major determinant of fish price is gear mix and month, since these influence the size and wholeness of the fish when landed, both of which I can control for. I observed quantities caught and registered by each fishing boat in Iceland, so I am not concerned about unobserved quantities that contribute to revenue.

choice:

$$d_{it} = 1 \implies R_{it} - \xi_{it}^R > c_{it}, \text{ and } t \in \mathcal{S}(q_i, \mathbf{z}_i, \mathbf{z}_t, c_i, \xi_i^R, \xi_i^q) \tag{52}$$

$$d_{it} = 0 \implies R_{it} - \xi_{it}^R < c_{it}, \text{ or } t \notin \mathcal{S}(q_i, \mathbf{z}_i, \mathbf{z}_t, c_i, \xi_i^R, \xi_i^q) \tag{53}$$

The following independence assumption is therefore crucial to identify cost characteristics separately from differences in expectations:

Assumption 6. *Forecast errors ξ_i^R and ξ_i^q are independent of daily production costs c_{it}, conditional on boat characteristics $\mathbf{z}_i$, day characteristics $\mathbf{z}_t$, and determinants of permit holdings q_i.*

Therefore boats do not systematically under- or over-predict with different quantity constraints or as days happen to be more or less costly. Moreover, I rule out dynamic dependence: early forecast errors do not change expectations later in the year. Under Assumptions 5 and 6, I can identify daily revenue and quantity expectations for all days t—whether boats went fishing or not—by regressing realized revenues and quantities on $\mathbf{z}_i$ and $\mathbf{z}_t$.

A.4 Identifying the crew size function

Assumption 7. *Let crew size be a flexible function of characteristics $\mathbf{z}_i$:*

$$L_{it} = L(\mathbf{z}_i) + \epsilon_{it}^L \tag{54}$$

where unobserved determinants of crew size ϵ_{it}^L are independent of q_i and $\mathbf{z}_i$.

The assumption rules out that variation in crew size conditional on $\mathbf{z}_i$ implies different profitabilities. It is not as strong as it appears in the fisheries context, so long as there is enough heterogeneity in $\mathbf{z}_i$. Crew sizes might vary because trainees are aboard, for example. I do not model gear choices, assuming they are fixed for the production process of a boat in a year, so the assumption implies that the total days at sea scale proportionally between the multiple gears they use. The assumption implies that average crew size across production days does not change with quantities, controlling for $\mathbf{z}_i$, a fact that holds true in the data. I can then estimate $L(\mathbf{z}_i)$ via regression of crew sizes on $\mathbf{z}_i$.

For the wage bill, I consider only single-boat firms and, with sufficient heterogeneity in $\mathbf{z}_i$, can relate harvest revenues to the wage bill by regression. This assumes taht unobserved determinants of the wage bill are

Assumption 8. *Total labor earnings or wage bill w_i depends on a share $\phi \in (0,1)$ of total realized harvest revenue $R_i = \sum_t R_{it}$:*

$$w_i = \alpha(\mathbf{z}_i) + \phi(\mathbf{z}_i) \cdot R_i + \epsilon_i^w \tag{55}$$

where unobserved determinants of the wage bill ϵ_i^w are independent of revenue forecast errors $\sum_t \xi_{it}^R$, conditional on $\mathbf{z}_i$.

I can then estimate the parameters of the revenue-sharing relationship $\alpha(\mathbf{z}_i)$ and $\phi(\mathbf{z}_i)$ via regression of wage bill on realized revenue, among single-boat firms.

I can then identify the ex-ante labor demand and ex-ante wage bill, i.e. how labor outcomes before within-year shocks are realized, using the day and revenue functions that I have identified. That is, expected labor demand for a quantity goal q_i is

$$\ell(q_i, \mathbf{z}_i) = L(\mathbf{z}_i) \cdot D(q_i, \mathbf{z}_i) \tag{56}$$

and the ex-ante wage bill is

$$w(q_i, \mathbf{z}_i) = E[w_i | q_i, \mathbf{z}_i] = \alpha(\mathbf{z}_i) + \phi(\mathbf{z}_i) \cdot \left(R(q_i, \mathbf{z}_i) - \sum_t \underbrace{E[\xi_{it}^R | q_i, \mathbf{z}_i]}_{=0} \right) \tag{57}$$

where the expected aggregate forecast shock $\sum_t E[\xi_{it}^R | q_i, \mathbf{z}_i]$ is zero by the independent assumption on forecast errors.

B Data Construction

B.1 Summary of fishery data

The fishery harvest and permit trading data consist of a fewer major data sources.

1. Fisheries Authority: Received from agency every permit transaction with associated vessel IDs, by species and date; landings in Iceland by day 1992- 2021 and monthly before 1992, for all fishing boats . Scraped from the agency website the permit prices for all species by day after 2001.

2. Transport Authority: vessel registry, with characteristics of vessel including owner history (firm or individual personal identifier), year of production, gear mix, size,

and "fate" (scraped, sold abroad, etc.); and crew registry, which registers crew members (using their individual personal identifier) for every day they are on a boat, but only for a subset of boats until 2011. Scraped from website. Vessels receive a unique vessel registry number (*skipaskrárnúmer*) when first brought to Iceland that stays the same even if ownership transfers.

3. Marine Research Institute: Received from agency catch data, which records every instance of harvesting fish at sea for a subsets of boats, including geographic coordinates, species, and gear use. Digitized by a research team at the agency from 1992 onward.

4. Pricing Authority for Catch Prices: Scraped from public website fish prices by region-month-gear-species bin.

5. Central Bank of Iceland: Received from former researchers permit price data and fish price data by month for every species, from 1992 onward.

6. National Archives of Iceland: Digitized some vessel and catch information from 1982 through 1992.

7. Statistics Iceland: access to labor data to match workers' earnings and employment history to fishing firms. See next section.

Firm exit. Figure B1 shows the number of fishing firms, by boat size. Permit trading spurred substantial firm exit; when each group of firms—first large- and medium-boat firms in 1992, then small-boat firms in 2002—were placed in permit markets, the number of firms fell by about 40%. There was also a wave of exits following a vessel buy-back program in the early 1990s (years marked in gray). Laxer regulations for small boats, according to a strict size threshold, creates an incentive to bunch at the regulatory threshold for boat size. When small and medium boats are placed in a permit market together in 2001, that incentive is removed, and so some firms substituted their small boat for a larger one. The current simulations take the fleet as given and do not model exit or boat switching.

B.2 Summary of administrative data

The labor market data consists of three major datasets. All are at the annual level:

1. Old pay-slip data from 1981 through 1997. These were digitized by Sigurdsson (2021) and give some basic demographic information (e.g. gender) as well as earnings information for each firm at which an individual worked in a year.

2. New pay-slip data from 1993 through 2021. These are collected by Statistics Iceland and give some basic demographic data as well as earnings information for each firm at which an individual worked in a year.

3. Tax returns from 1989 through 2021. These give more detailed demographic information (highest degree, marital status, number of children, postal code of residence, born abroad/in Iceland) as well as total taxable earnings (labor income), tax burden, and a series of government transfers like pensions and unemployment assistance.

I receive all information from these datasets for individuals who ever worked on fishing boats (defined below). I also receive a random cross-section of 10% of the remaining observations, i.e. a random set each year of individuals who never worked on fishing boats. Thus it is not a panel of individuals.

B.3 Identifying the set of fishery workers

The fishery workers are identified in tax data using their national identification numbers (*kennitala*) from the following sources:

1. The crew registry kept by the Icelandic Transport Authority (*Samgöngustofa*), which registers individuals by their personal identifiers on the days on which they are at sea. This registry becomes more comprehensive over time. Ranked positions (captain, first mate, engineers) on the largest boats (> 50 gross tonnes) are tracked starting in 1981. All crew-members on large boats are added in 1986. The registry requirement decreased its size threshold in 1992, such that all crews for large boats (> 6 GT) were tracked in the 1990s. Ranked positions on small boats (< 6 GT) were added in 2001. The crew registry covered every person on a fishing boat starting in 2011.

2. Annual pay-slips given by each firm on their workers, which I received from Statistics Iceland from 1981 through 2021. Those pay-slips separately record earnings from fishing boats.

3. Annual tax returns for all workers, which I received from Statistics Iceland from 1988 through 2021. From 1988 through 1994 and 1997 through 2014, there was a

tax exemption for workers on fishing boats. In 1995, the tax returns flagged the days at sea for fishing boat workers, which were used that year for tax exemption calculations.

Any individual ever recorded in the crew registry, receiving fish earnings, or receiving the tax exemption are flagged as ever working in the fishery. For these workers, I receive all years they appear in the labor market datasets mentioned above, regardless of whether they are working in the fisheries.

Individuals appearing in the crew registry can be linked directly to each fishing trip on each boat. Those linked using the tax exemptions—including small-boat workers for my period of study—are linked by firm identifiers in the tax and payslip data.

B.4 Constructing cod-equivalent harvests

The Icelandic fisheries management scheme consists of many species, each with their own cap. To allow for the exchange of species permits, the government has instituted species exchange rates (*þorskígildisstuðlar*) that convert a kg of each species permit to cod-equivalent units (*þorskígildi*). These exchange rates are set by the Fisheries Ministry for each regulatory year t, which starts September 1. It is based on the average unit price of each species relative to that of cod from May 1 of the previous calendar year to April 30 of the current calendar year t. For example, if the average unit price of cod was 120 Icelandic krónur per kg (i.e. total revenue divided by total harvests), and the average unit price of haddock was 60 ISK per kg, then each kilogram of haddock in permits or harvests is 0.5 cod-equivalent kilograms.

Importantly for my analysis, the production requirement binds at the cod-equivalent level: boats must harvest half their permit allocation in cod-equivalent units. Therefore harvest and permit quantities throughout the analysis are in cod-equivalent kg or metric tons (1,000 kg).

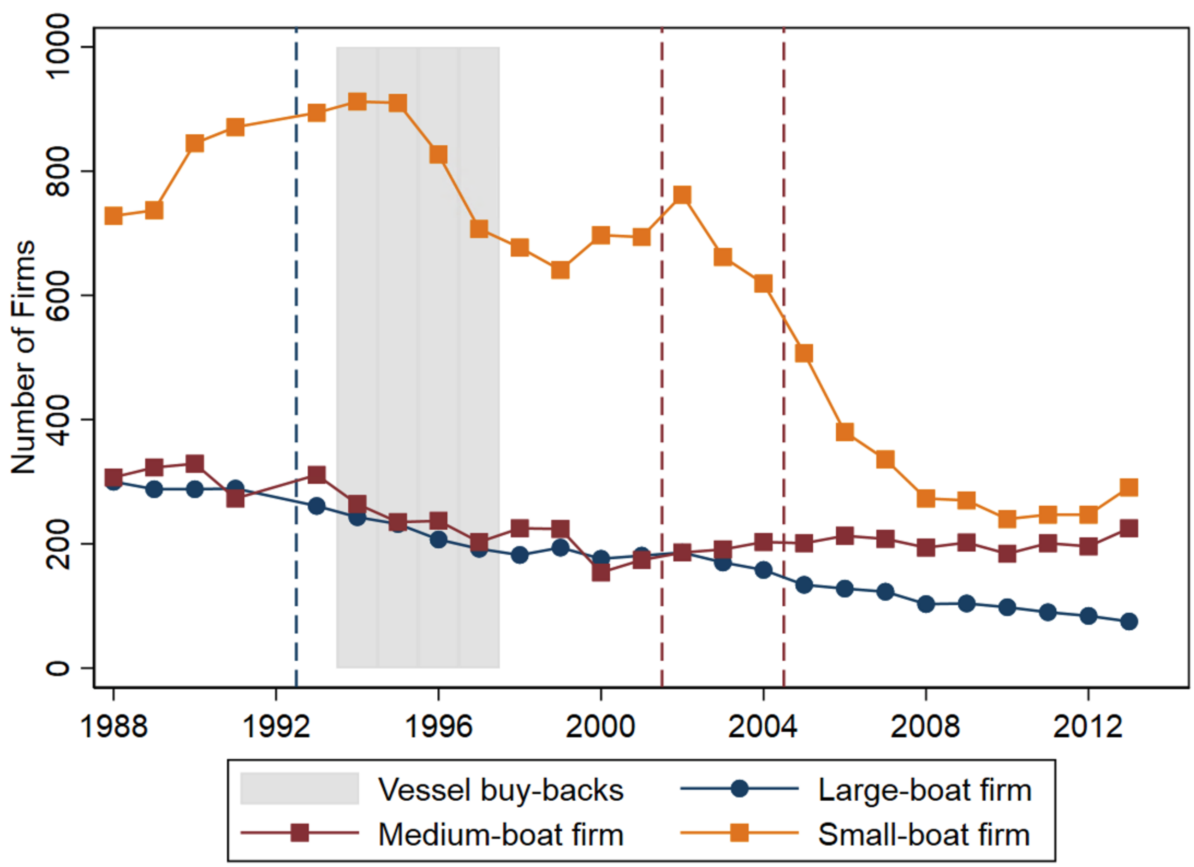
I collect species exchange rates from the website of the Iceland Fisheries Authority (*Fiskistofa*) and, for earlier years, from regulatory announcements by the Fisheries Ministry in the Icelandic government register (*Reglugerðarsafn*). I then multiply the quantities of each species by these exchange rates to create cod-equivalent harvests and permit amounts.

B.5 Constructing annual permit rental price

Permits are traded throughout the year in markets for different species. The structural model, however, assumes one period of trading in the year, and I consider uni-dimensional quantities in cod-equivalent units. Therefore, my measure of each year's permit rental price is the average permit price across all transactions in all species, weighted by the transaction amount in cod-equivalent kilograms.

The model therefore does not account for price dispersion in the year, which, along with the presence of brokers, is an indication of search frictions. The average permit market at the species-year level has a coefficient of variation of 0.335, with an average of 0.111 in cod permit markets where most transactions take place. The coefficients of variation are on average 37% higher in small-boat permit markets. These are similar in magnitude to other markets where search frictions have been studied: 0.19 to 0.25 (retail wine), 0.20 to 0.24 (waste hauling), and 0.22 (prescription medication) (Sorensen 2000; Jaeger and Storchmann 2011; Salz 2022). Comparing another environmental market, Shapiro and Walker (2024) calculate a coefficient of variation of 1.04 in the average pollution offset market they study, larger by an order of magnitude.

Appendix Figure B1. Number of firms over time



Note: This figure shows the number of firms over time, split by whether it is a large-, medium-, or small-boat firm, with notable exit rates in the years after the expansion of the permit market. In gray is a prominent vessel buy-back program targeted at small boats. Large and medium boat firms were placed in a permit market in 1992, while small boat firms were placed in a permit market with medium boat in 2001, with a few remaining grandfathered in the old system until 2004. There is a small uptick in medium boat firms after 2001 due to small-boat firms replacing their boats with medium-sized boats.

C Details on Estimation

C.1 Estimating day choice: method of simulated moments

Here is an outline of the method of simulated moments. Recall that the mean and variance of the daily cost distribution are gear-mix-specific functions of boat size. If g is the gear mix of the boat, then

$$\mu(\mathbf{z}_i) = \alpha_1^g + \alpha_2^g \cdot \log(\text{boat size}) \tag{58}$$

$$\sigma(\mathbf{z}_i) = \alpha_3^g + \alpha_4^g \cdot \log(\text{boat size}) \tag{59}$$

For any proposed cost parameters $\{\hat{\alpha}\}$,

1. Calculate $\hat{\mu}_i = \hat{\alpha}_1^{g_i} + \hat{\alpha}_2^{g_i} \cdot \log(\text{boat size}_i)$ and $\hat{\sigma}_i = \hat{\alpha}_3^{g_i} + \hat{\alpha}_4^{g_i} \cdot \log(\text{boat size}_i)$, given boat i's gear mix g_i and its boat size.

2. Take S draws of the cost shock vector, where, for each simulation $s \in S$, there is a vector $c_i(s)$ of T draws from $c_{it} \sim^{iid}$ Log-normal$(\hat{\mu}_i, \hat{\sigma}_i)$. T is the total possible days at sea. For each simulation s,

   (a) Use the realized cost vector $c_i(s)$ to calculate the vector of daily profits $\pi_i = \{\pi_{it}\}_{t=1}^T$, where $\pi_{it} = \hat{R}_{it} - c_{it}$, where $\hat{R}_{it}$ is the result of the regression on daily revenues.

   (b) Form the ordered set of days $\{t_{(k)}\}$ by ranking all days with $\pi_{it} \geq 0$ by their daily profits π_{it}. Denote the corresponding expected harvests as $\{q_{i(k)}\}$. Denote the corresponding expected revenues as $\{\hat{R}_{i(k)}\}$.

   (c) Take the set of most profitable days until expected harvests are equal to permit holdings: $\sum_{m=1}^k q_{i(m)} = q_i$, where q_i is post-trading permit holdings for boats in the permit market and is the total cod permits for boats under non-tradeable cod permits (small boats before 2000). Call this set $\mathcal{S}_i^s$.

   (d) Re-order the set of expected daily revenues $\{\hat{R}_{i(k)}\}$ from highest to lowest among days in $\mathcal{S}_i^s$. Call this the marginal revenue curve $\hat{R}_i^s = \{\hat{R}_{i(n)}\}$, i.e. the expected daily revenues of the chosen days and (n) denotes the ranking from highest to lowest revenue.

3. Collect the simulated moments $g(\hat{\alpha})$:

   (a) The expected daily revenue of the 1st through T'th highest revenue days: $R_{i(n)}(\hat{\alpha}) =$

$\frac{1}{S}\sum_s \hat{R}^s_{i(n)}$ for all ranks (n). These represent T moments, which can be zero. The empirical counterpart is $\hat{R}_{i(n)}$.

(b) The total number of days at sea: $D_i(\hat{\alpha}) = \frac{1}{S}\sum_s |\mathcal{S}^s_i|$. The empirical counterpart is $\hat{D}_i$.

4. The objective function is the squared distance between the simulated moments and the empirical moments:

$$Q(\hat{\alpha}) = [g(\hat{\alpha}) - \hat{g}]W'[g(\hat{\alpha}) - \hat{g}] \tag{60}$$

where W is a weighting matrix.

I then search for cost parameters α that minimize $Q(\alpha)$. I use the two-step optimal weight matrix for W.

C.2 Constructing the profit functions

For each gear mix (which impacts costs and revenue/quantity expectations) and region (which impacts revenue/quantity expectations),

1. Set a grid of boat sizes and quantities, namely an even grid of values from the minimum to maximum for boats with that gear mix in that year.

2. Simulate cost draws using the estimates of the cost distribution $\hat{F}_{c|\mathbf{z}}$. Save total profits, i.e. $\Pi^s_i = \sum_t \pi_{it}$ for chosen days under the cost draw s. Also save the total days at sea D^s_i as before. Labor earnings rely on harvest revenues, so I sum these up separately as well: R^s_i.

3. Average across all simulations to find harvest profits $\Pi(q_i, \mathbf{z}_i)$, day choice $D(q_i, \mathbf{z}_i)$, and revenues $R(q_i, \mathbf{z}_i)$ for this gear mix-size-quantity combination.

4. Interpolate across quantity-size grid points with cubic splines.

5. Calculate marginal profits as the numerical derivative $\partial\Pi(q_i, \mathbf{z}_i)/q_i$ using the interpolation.

C.3 Estimating market parameters: F_Δ and the transaction cost function

For a guess of parameters $\theta = (\mu_\Delta, \sigma_\Delta, \alpha, \beta, \eta)$,

1. Calculate $\frac{\partial}{\partial q_i} TC(\bar{q}_i - q_i)$ for each boat i using the permit allocation and post-trade permit holdings.
2. If i's permit holdings q_i are not in the bunching range (defined as 50%-60% of permit allocation $\bar{q}_i$),
   (a) Calculate

$$\Delta_i = \frac{1}{r_i}\left(\frac{\partial}{\partial q_i}\Pi(q_i, \mathbf{z}_i) - \frac{\partial}{\partial q_i}TC(q_i, \bar{q}_i)\right) \tag{61}$$

   where r_i is the weighted average permit price for the year for i's permit market, where weights are the transacted volume of permits in cod-equivalent units.

   (b) Standardize the value to $\tilde{\Delta}_i = (\exp(\Delta_i) - \mu_\Delta)/\sigma_\Delta$
   (c) Then i's individual likelihood is

$$p_i = \Pr(\Delta_i|\theta) = \phi(\tilde{\Delta}_i) \tag{62}$$

   where ϕ is the probability density function of the standard normal.

3. If i's permit holdings are in the bunching range,
   (a) Calculate the threshold

$$\bar{\Delta}_i = \frac{1}{r_i}\left(\frac{\partial}{\partial q_i}\Pi(\bar{q}_i/2, \mathbf{z}_i) - \frac{\partial}{\partial q_i}TC(\bar{q}_i/2)\right) \tag{63}$$

   (b) Standardize the threshold to $\tilde{\bar{\Delta}}_i = (\exp(\bar{\Delta}_i) - \mu_\Delta)/\sigma_\Delta$
   (c) Then i's individual likelihood is

$$p_i = \Pr(i \text{ bunches}|\theta) = \Phi(\tilde{\bar{\Delta}}_i) \tag{64}$$

   where Φ is the cumulative distribution function of the standard normal.

4. Then calculate the log likelihood

$$\mathcal{L}(\theta) = \sum_i \log p_i \tag{65}$$

I then find θ that maximizes $\mathcal{L}(\theta)$.

Bootstrapping standard errors. I construct standard errors for the coefficients by running the estimation procedure on 75 bootstrapped samples.

C.4 Parameter estimates

Tables C1 and C3 give the cost and market parameter estimates, respectively. Bootstrapped standard errors are reported in parentheses.

C.5 Model fit

In this section, I summarize a series of model fit exercises. First I focus on two variables in the production process: the days at sea and the daily revenue curve. Figure C1(a) plots the number of days at sea; the model-implied values match closely, though with a slight underprediction at the top. A regression of the actual days on the model-implied days gives an R^2 of 97%. Figures C1(b) and (c) then compare the expected daily revenue of each chosen day in the data and model, where (b) plots every day while (c) shows the binned scatter-plot compared to the 45-degree line. The model fit is close on average, though sub-figure (b) shows that the model predicts that boats choose higher-revenue days than they actually do in the data. This could be because of unobserved cost differences across days (e.g. wintery conditions) that I do not currently control for.

I next turn to the fit of the permit market decisions. Table C4 shows the model-implied non-trading rates (defined as post-trading permit holdings within 99.5%-100.5% of permit allocations) and the bunching rate (defined as having post-trading permit holdings within 50%-60% of permit allocations). This is among boats in the permit market and therefore excludes small boats before 2001. In most years, the model under-predicts the share of boats that do not trade, though the non-participation rates overall are small. It also under-predicts the bunching rate in most years.

Figure C1(d) plots the model-implied permit choice against the permit holdings in the data. It shows the line of best fit for values about $q = \exp 9$ to emphasize that the fit is sensible except for boats with small permit holdings in the data. Among these boats, the model vastly over-predicts the permit holdings. This is not an artifact of ignoring boats under 50% of the permit allocations, since I only estimate the market parameters on boats above the 50% cutoff (assuming that those below are exiting and are not affected by the rule). A regression of the log of model-implied pemrit holdings on actual log permit holdings has an R^2 of 74% overall and 81% at higher levels. Sub-figures (e) and (f) show the binned scatter plot of permit choice (both model-implied and actual) against permit allocation. These emphasize two facts: first, that the model over-predicts permit choices for boats of low allocations by an entire log point. This indicates that the small estimated transaction costs do not fit the data at the bottom of the distribution. Second, the model under-predicts permit choices for small boats across the entire distribution. This could be because the determinants of permit choice are not market-specific and do not relate to size; that is, the Δ_i and transaction cost function $TC(\bar{q}_i - q_i)$ have no relation to boat characteristics.

In line with the over-prediction of permit demand among small boats, the model implies aggregate permit demand (at the observed permit prices) within 5% of actual aggregate permit demand in the big-boat market (1.79 vs. 1.70 million tons across all years). In the small-boat market, however, I over-predict aggregate permit demand by 57% (246 vs. 156 thousand tons).

D Details on Construction of Counterfactuals

D.1 Finding counterfactual equilibrium permit prices

Here I outline the algorithm by which I calculate new equilibrium permit prices. Let

$$\bar{Q}^0 = \sum_{i \in n} \tilde{q}(r_n, \mathbf{z}_i, \bar{q}_i)$$

be the aggregate number of permits chosen in the model at the observed permit price r_n for market n (small- vs large-boat vs unified permit market). For the unified market counterfactual, use the aggregate number of permits across boat markets. For the no production requirement counterfactual, use the unconstrained permit choice function $q(r_n, \mathbf{z}_i, \bar{q}_i)$. Starting at the observed price r_n,

1. Consider a new candidate price r'. Aggregate each boat's permit choice to find aggregate permit choice $\bar{Q}(r')$.

2. If $\bar{Q}(r') > \bar{Q}^0$ (excess demand), find a new candidate price $r'' = r' + s$. If $\bar{Q}(r') < \bar{Q}(r')^0$ (excess supply), find a new candidate price $r'' = r' - s$. Find the new aggregate choice $\bar{Q}(r'')$. Then,

   (a) If $|\bar{Q}(r'') - \bar{Q}(r')| < \text{tol} \cdot \bar{Q}^0$, stop. I set tol to 0.001, i.e. 0.1% of the actual aggregate number of permits.

   (b) Otherwise, if $\bar{Q}(r'') - \bar{Q}(r')$ is the same sign as $\bar{Q}(r') - \bar{Q}^0$, let the new step size be the same: $s' = s$. If it is of opposite sign, halve the step size: $s' = s/2$. Repeat process with new candidate price $r''' = r'' + s'$.

D.2 Calculating aggregate permit supply and demand

To calculate the excess permit supply and demand functions that determine the permit price in competitive equilibrium, I take a grid of permit prices and use the permit choice functions and permit allocations. For any r,

1. Calculate permit choice $q(r, \mathbf{z}_i, \bar{q}_i)$ for all i in the market, under the actual or counterfactual design.

2. Find the excess demand or excess supply of each participant i in the market:

$$q_i^d(r) = \max\{0, q(r, \mathbf{z}_i, \bar{q}_i) - \bar{q}_i\}$$

$$q_i^s(r) = \max\{0, \bar{q}_i - q(r, \mathbf{z}_i, \bar{q}_i)\}$$

3. Aggregate permit demand and supply are therefore

$$\mathcal{D}(r) = \sum_i q_i^d(r)$$

$$\mathcal{S}(r) = \sum_i q_i^s(r)$$

The graphs then trace the two curves for each market.

Appendix Table C1. Cost parameters grouped by gear type

Gear types 1 through 4						Gear types 5 through 7				
Gear mix	Year	α_1^g	α_2^g	α_3^g	α_4^g	Gear mix	Year	α_1^g	α_2^g	α_3^g
1	1999	-0.020	0.149	0.865	0.057	5	1999	-0.410	0.077	1.647
		(0.001)	(0.002)	(0.001)	(0.001)			(0.002)	(0.001)	(0.003)
	2000	-0.021	0.127	0.715	0.049		2000	0.699	0.157	10.140
		(0.001)	(0.001)	(0.002)	(0.001)			(0.001)	(0.002)	(0.014)
	2001	0.311	0.169	0.745	0.065		2001	0.303	0.109	1.582
		(0.004)	(0.003)	(0.004)	(0.001)			(0.002)	(0.002)	(0.012)
	2002	-0.076	0.107	0.510	0.030		2002	-1.543	0.596	0.460
		(0.001)	(0.002)	(0.003)	(0.001)			(0.042)	(0.002)	(0.004)
	2003	-0.346	0.034	0.219	0.093		2003	-1.501	0.569	0.361
		(0.002)	(0.001)	(0.003)	(0.001)			(0.070)	(0.005)	(0.002)
	2004	-0.662	0.077	0.682	0.041		2004	-0.985	0.463	0.071
		(0.009)	(0.001)	(0.004)	(0.001)			(0.007)	(0.001)	(0.001)
2	1999	0.318	0.134	0.810	0.046	6	1999	0.287	0.076	0.546
		(0.003)	(0.001)	(0.005)	(0.001)			(0.003)	(0.001)	(0.004)
	2000	0.041	0.072	0.539	0.077		2000	0.622	0.124	1.135
		(0.001)	(0.001)	(0.008)	(0.001)			(0.002)	(0.003)	(0.069)
	2001	0.563	0.113	0.547	0.078		2001	0.713	0.073	0.553
		(0.004)	(0.002)	(0.003)	(0.001)			(0.004)	(0.001)	(0.008)
	2002	-0.092	0.079	0.265	0.073		2002	-0.541	0.482	4.629
		(0.001)	(0.001)	(0.003)	(0.001)			(0.004)	(0.002)	(0.044)
	2003	-0.163	0.075	0.541	0.073		2003	-3.037	0.979	3.061
		(0.002)	(0.001)	(0.005)	(0.001)			(0.092)	(0.002)	(0.088)
	2004	0.095	0.076	0.333	0.080		2004	-3.031	1.019	4.481
		(0.001)	(0.001)	(0.004)	(0.001)			(0.045)	(0.024)	(0.076)
3	1999	-0.624	0.107	0.942	0.061	7	1999	-4.064	1.437	3.155
		(0.003)	(0.002)	(0.004)	(0.001)			(0.032)	(0.021)	(0.042)
	2000	-0.781	0.088	0.847	0.079		2000	4.381	0.514	1.560
		(0.004)	(0.001)	(0.005)	(0.001)			(0.040)	(0.002)	(0.025)
	2001	-0.384	0.099	0.742	0.059		2001	1.194	0.146	7.744
		(0.004)	(0.001)	(0.006)	(0.001)			(0.033)	(0.002)	(0.045)
	2002	-1.784	0.024	1.258	0.090		2002	-3.513	1.346	5.013
		(0.062)	(0.001)	(0.040)	(0.003)			(0.071)	(0.021)	(0.049)
	2003	-0.941	0.052	0.309	0.074		2003	-0.370	0.244	6.092
		(0.007)	(0.001)	(0.006)	(0.001)			0.004)	(0.003)	(0.065)
	2004	-1.189	0.069	-0.095	0.057		2004	4.356	0.299	7.790
		(0.033)	(0.001)	(0.002)	(0.002)			(0.027)	(0.007)	(0.055)

Note: The table reports estimates for parameters determining the mean and variance of the distribution of daily production cost shocks, for each year and gear mix. Bootstrapped standard errors are in parentheses. Appendix Section C details the estimation procedure.

Appendix Table C2. Market parameters

Year	μ_Δ	σ_Δ	α	η	β
1999	-0.60	0.52	-0.93	-2.83	-11.16
	(0.003)	(0.004)	(0.005)	(0.072)	(0.120)
2000	-0.52	0.53	0.11	-14.35	-16.64
	(0.004)	(0.005)	(0.002)	(0.223)	(0.334)
2001	-0.31	0.29	0.71	-3.96	-15.70
	(0.004)	(0.002)	(0.004)	(0.048)	(0.402)
2002	-0.17	0.47	-0.96	-2.04	-17.02
	(0.005)	(0.008)	(0.011)	(0.068)	(0.508)
2003	0.12	0.69	-3.17	-1.47	-18.86
	(0.003)	(0.009)	(0.088)	(0.072)	(0.772)
2004	1.03	-0.65	1.13	-1.30	4.35
	(0.042)	(0.007)	(0.092)	(0.072)	(0.122)

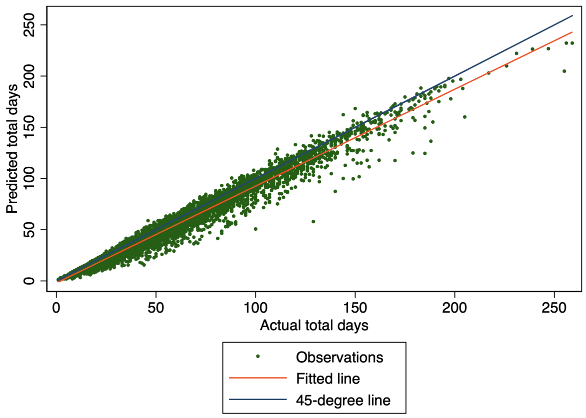
Note: The table reports estimates for parameters of the residual wedge Δ_i between the permit price and marginal profits, as well as the parameters of the transaction cost function. Bootstrapped standard errors are in parentheses. Appendix Section C details

Appendix Table C3. Influence of Designs

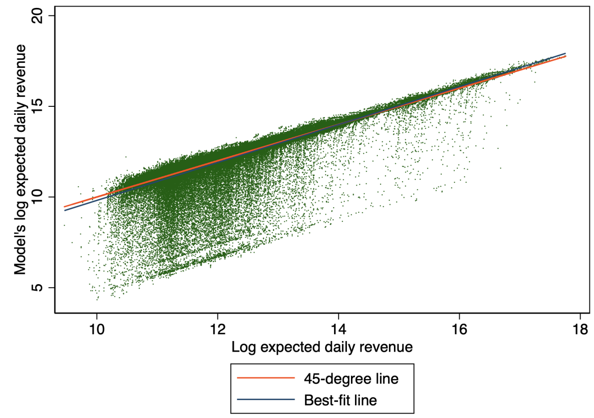
Year	Design	Actual (1)	Segmented, no limit (2)	Unified, with limit (3)	Unified, no limit (4)
1999	Gains from trade (billion ISK)	2.84	3.93	-	-
	Person-days, targeted boats (thousand)	35.36	29.73	-	-
	Wage bill on targeted boats (billion ISK)	1.51	1.24	-	-
	Harvest share of small/medium boats	-	-	-	-
	Harvest profits of small/medium boats	-	-	-	-
	Permit price	77.0	45.1	-	-
2000	Gains from trade (billion ISK)	3.91	5.70	-	-
	Person-days, targeted boats (thousand)	20.77	17.69	-	-
	Wage bill, targeted boats (billion ISK)	1.11	0.96	-	-
	Harvest share of small/medium boats	-	-	-	-
	Harvest profits of small/medium boats	-	-	-	-
	Permit price	100.9	62.5	-	-
2001	Gains from trade (billion ISK)	5.16	5.42	5.59	5.92
	Person-days, targeted boats (thousand)	26.49	20.33	26.50	19.93
	Wage bill, targeted boats (billion ISK)	1.07	0.90	1.07	0.90
	Harvest share of small/medium boats	0.11	0.11	0.10	0.09
	Harvest profits of small/medium boats	3.24	3.25	2.99	2.91
	Permit price	111.1, 84.7	104.8, 77.7	106.6	100.0
2002	Gains from trade (billion ISK)	4.09	5.38	4.13	5.35
	Person-days, targeted boats (thousand)	38.35	32.49	38.38	32.44
	Wage bill, targeted boats (billion ISK)	2.50	2.30	2.50	2.30
	Harvest share of small/medium boats	0.17	0.17	0.15	0.16
	Harvest profits of small/medium boats	4.75	4.83	4.46	4.81
	Permit price	89.9, 69.0	61.2, 60.3	84.7	61.2
2003	Gains from trade (billion ISK)	3.69	4.41	3.96	4.72
	Person-days, targeted boats (thousand)	39.49	29.99	39.50	29.94
	Wage bill, targeted boats (billion ISK)	1.20	0.99	1.20	1.00
	Harvest share of small/medium boats	0.17	0.16	0.15	0.14
	Harvest profits of small/medium boats	4.72	4.80	4.31	4.38
	Permit price	74.0, 49.0	61.5, 41.8	68.4	57.2
Total	Gains from trade (billion ISK)	19.69	24.84	13.68	16.00
	Person-days, targeted boats (thousand)	160.46	130.23	104.38	82.31
	Wage bill, targeted boats (billion ISK)	7.39	6.39	4.77	4.20
	Harvest share of small/medium boats	0.15	0.15	0.13	0.13
	Harvest profits of small/medium boats	12.71	12.88	11.76	12.10

Note: The table shows the gains from trade and four key outcomes for the permit market as designed and from simulated markets without the two trading limits I study: the production requirement and segmentation. For the production requirement, the relevant outcomes are the labor demand and earnings on the targeted boats, i.e. the boats that bunch at 50% of their permit allocation in the actual market. For segmentation, the outcomes are the harvest share and profits of boats in the small-boat market, which includes boats under 6 gross tons that were exempt from permit trading until 2001 and medium-sized boats who were placed in their permit market in 2002. It then sums the values in the final rows.

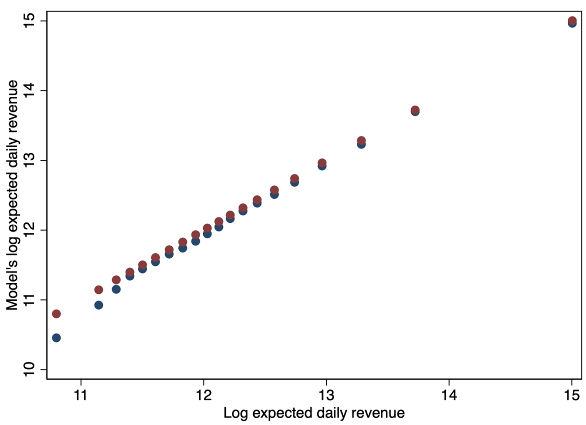
Appendix Figure C1. Model fit: production



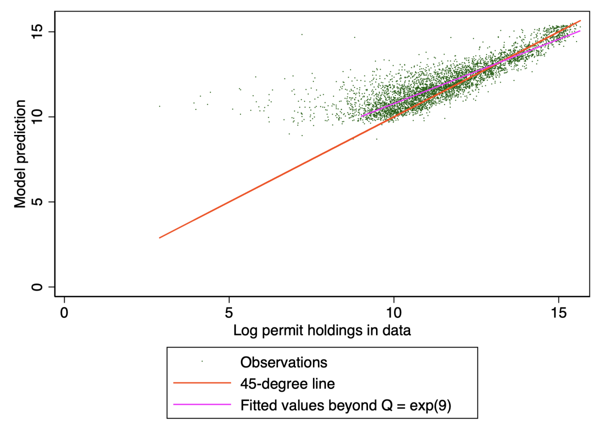
(a) Number of days



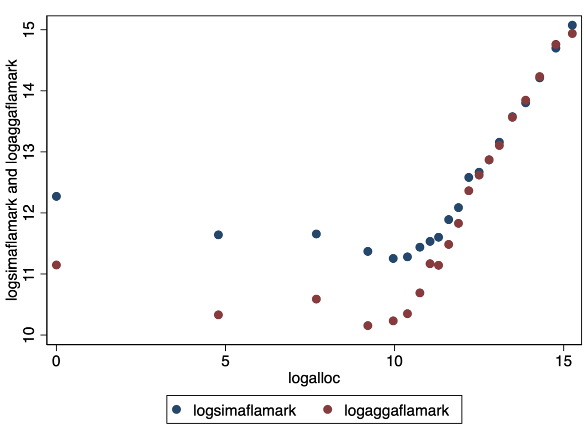
(b) Daily revenue



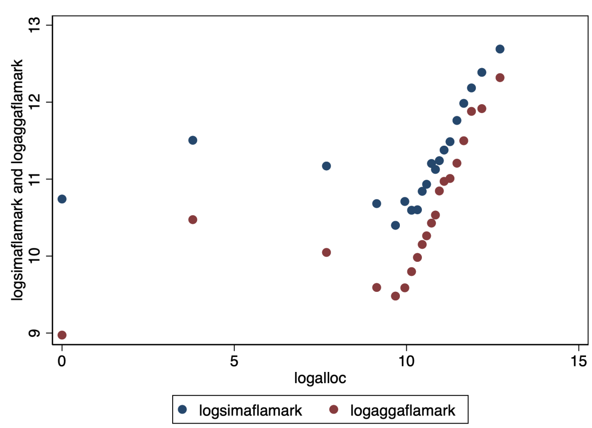
(c) Binned scatter: Daily revenue



(d) Permit choice



(e) Permit choice by allocation, big boats

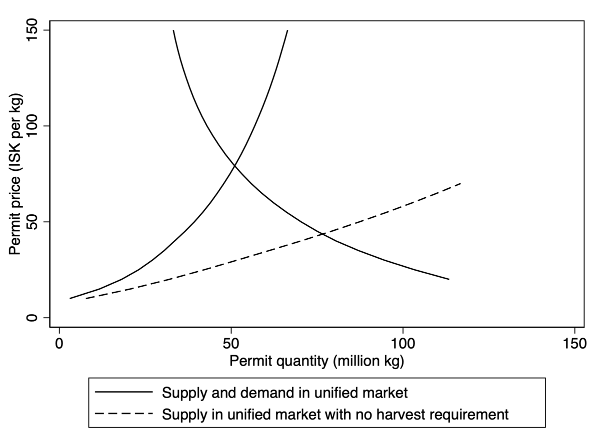


(f) Permit choice by allocation, small boats

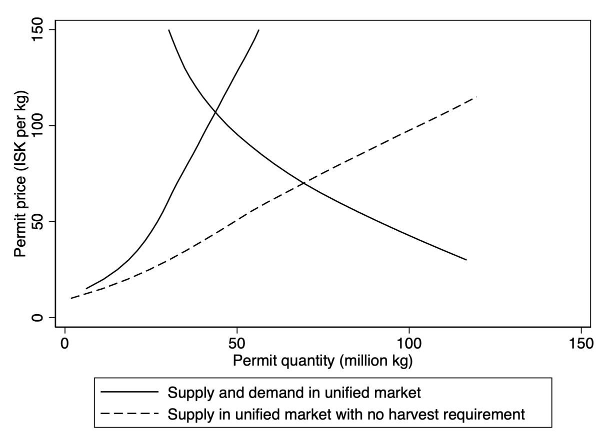
Appendix Table C4. Comparison of Participation and Bunching Rates

Year	Model's fraction with no trading	Actual fraction with no trading	Model's bunching rate	Actual bunching rate
1999	0.021	0.037	0.098	0.076
2000	0.020	0.025	0.101	0.048
2001	0.014	0.065	0.044	0.117
2002	0.017	0.055	0.055	0.118
2003	0.008	0.049	0.060	0.155
2004	0.019	0.032	0.070	0.178

Appendix Figure D1. Impact of trading limits: 1999 and 2000

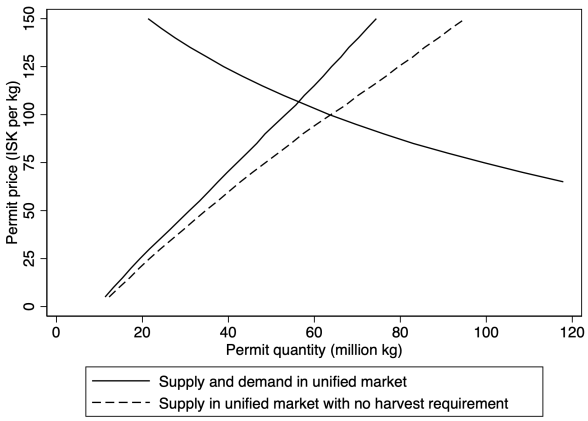


(a) 1999

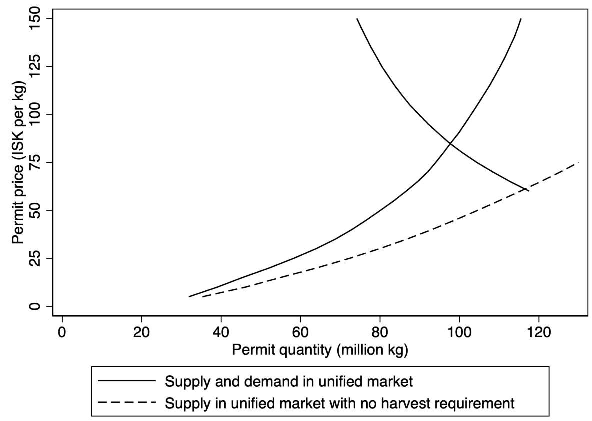


(b) 2000

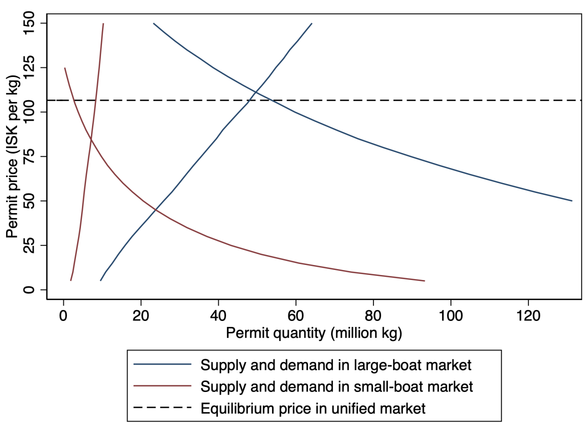
Appendix Figure D2. Impact of trading limits: 2001 and 2002



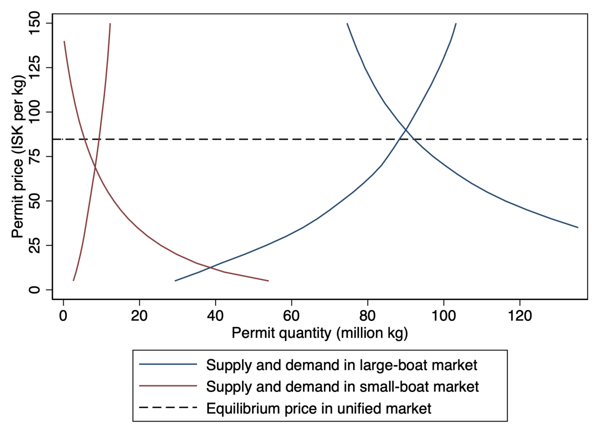
(a) Harvest rule, 2001



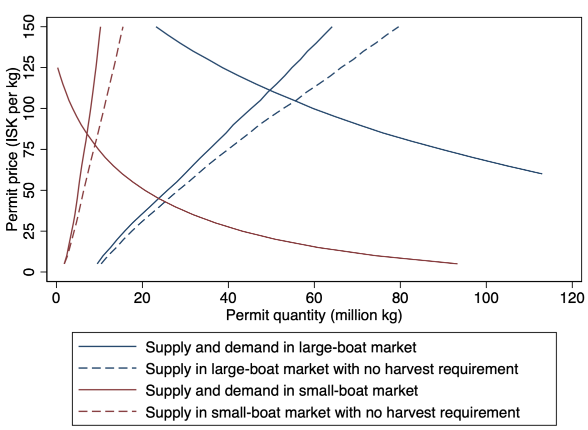
(b) Harvest rule, 2002



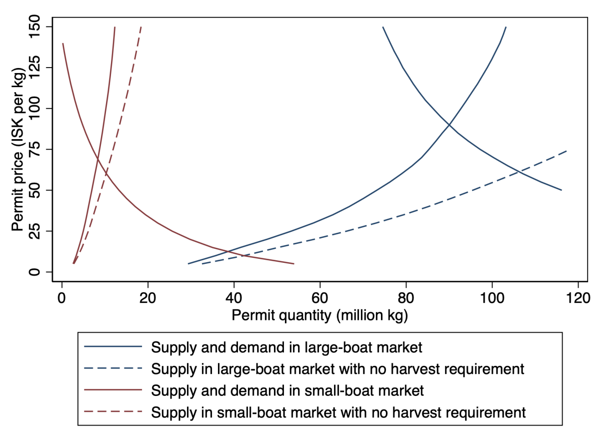
(c) Segmentation, 2001



(d) Segmentation, 2002

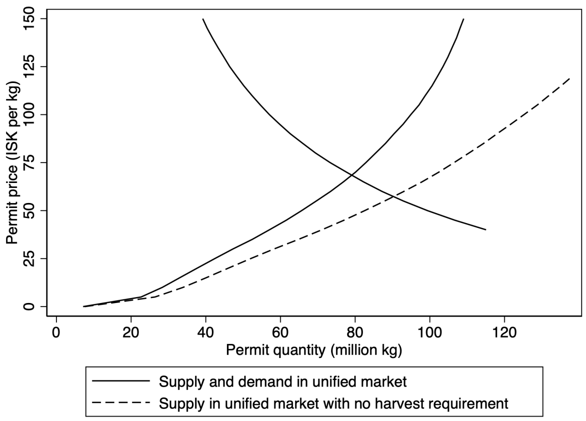


(e) Harvest rule in segmented market, 2001

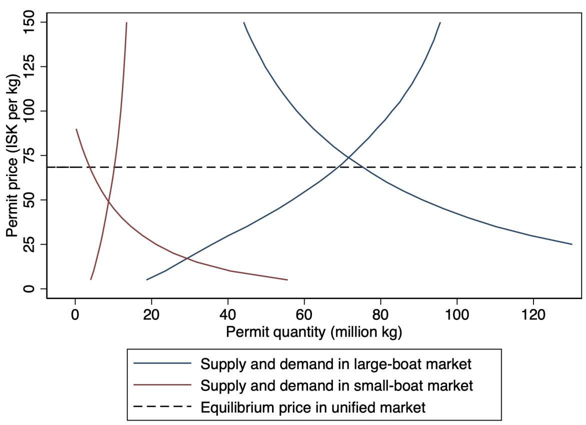


(f) Harvest rule in segmented market, 2002

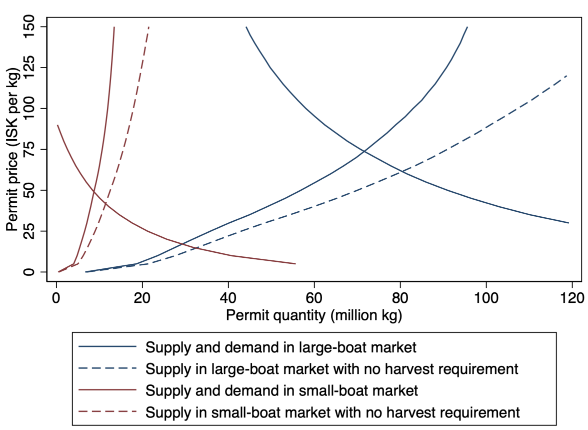
Appendix Figure D3. Impact of trading limits: 2003 and 2004



(a) Harvest rule, 2003



(b) Segmentation, 2003



(c) Harvest rule in segmented market, 2003