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GRANDFATHERING WITH ANTICIPATION

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ABSTRACT

Natural resources such as carbon, water, and fish are increasingly managed with markets that require an initial allocation of property rights. In practice these rights are typically grandfathered based on historical use, but rights could be allocated any number of ways. Taking the perspective of a currently unregulated firm, we ask how the anticipation of a future market affects extraction incentives, environmental quality, and welfare prior to the implementation of the market. We show that this anticipation has first-order welfare implications, seemingly contradicting the widely held belief that the allocation of rights has no aggregate welfare consequences. The most egregious case involves anticipation of a traditional grandfathering rule, which induces a race for allocation before the market goes into effect, causing over-extraction or over-emissions, even relative to the completely unregulated baseline. We derive an alternative allocation rule called "Reverse-Grandfathering" that still provides a free allocation of rights but reverses the marginal incentive to emit or extract. We show that this new approach, which relies on incentives due to anticipation, can replicate welfare-maximizing firm behavior, even in the complete absence of regulation. To illustrate the potential magnitude of anticipation effects, we develop and parameterize a structural model of a hypothetical market among nearly 5,000 large fishing firms on the high seas. Relative to traditional grandfathering and auctioning of rights, Reverse-Grandfathering substantially increases natural resource stocks and welfare.

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1 Introduction

Markets for environmental goods and services rely on transferable rights to emit a pollutant or extract a natural resource. Although the settings vary, the basic institution involves setting an emissions or extraction cap, allocating rights to firms, and then allowing the rights to be traded among firms. The main allure of a market-based approach to environmental protection is that for any initial allocation of rights, trading ensures that the environmental target is achieved at least cost.

The initial allocation of rights is a critical first step. For example, air pollution markets require allocating emissions rights across firms; water markets require establishing farm-level allowable extraction rates; and carbon offset markets require establishing baselines against which further sequestration can be measured and traded. While the initial allocation of rights is important for distributional reasons, it is often given short shrift by economists on the grounds that it represents a transfer with no aggregate welfare implications; this intuition leans heavily on the Independence Axiom in Coase (1960). In this paper we argue, to the contrary, that the *anticipation* of a future allocation of rights in an environmental market has first-order effects on behavior, welfare, and environmental quality. We go further to argue that anticipation of a future environmental market will often deliver welfare and environmental outcomes that are substantially worse than the no-regulation counterfactual. In other words, the very idea that a future market could arise is likely to reduce environmental quality and welfare, seemingly delivering the opposite of the market's intended effect.

Take, for instance, the case of unregulated groundwater extraction by farmers, where over-exploitation has become the norm. Suppose these currently-unregulated farmers suddenly *anticipate* a future in which extraction rights will be traded in a market.[1] In practice, such rights are often "grandfathered" proportionately to historical extraction rates: The more a farmer has extracted in the past, the greater is her allocation once the market is implemented. Anticipating such an allocation rule, existing farmers are incentivized to extract even more than is myopically profitable in order to gain a larger future allocation. This incentive arises from the *anticipation* of the future allocation rule and has substantial welfare and environmental consequences that have largely gone unnoticed. Indeed, the promise of a future market – ostensibly designed to correct market failures – can actually have the opposite effect, owing entirely to the anticipation of the future allocation of rights. Given the proliferation of market-based policies around the world, existing unregulated firms may increasingly anticipate a transition to an environmental market in the future, suggesting that this phenomenon could be playing out today.

While we address the challenge of anticipation in general, the case of grandfathering is particularly salient due to its widespread use.[2] Grandfathering is an allocation approach in which initial rights to extract a resource or emit pollution are granted

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[1] This example is currently playing out in California, which has recently passed, but has not yet implemented, new rules on groundwater extraction.

[2] The term *grandfathering* is itself controversial, because it originates from so-called "Grandfather Clause" in legislation and constitutional amendments in the southern U.S. during the Jim-Crow-Law era of the late-1800s. In order to suppress voting, particularly among newly-freed slaves and their ancestors, literacy tests and poll taxes were introduced. But because these impediments were deemed overtly discriminatory to all poor voters, legislators included a loophole: An exemption was granted for individuals whose *grandfather* had voted in past elections. This facilitated voting by poor white voters, but excluded poor black voters.[3] While the grandfather clause was ultimately deemed unconstitutional, the name stuck and over time the use of "grandfathering" extended to laws and contracts in a wide variety of settings.

in proportion to historical patterns. Indeed, this practice often has a well-reasoned rationale. It may be politically expedient because it confers the greatest rights to those who have historically valued, and invested in, the resource. Similarly, there could be political economy considerations that promote grandfathering over auctions or other alternatives. These potential benefits notwithstanding, we argue that grandfathering, and indeed any allocation rule, has consequences for ex-ante behavior, and thus may have important welfare implications. This seems to contradict the widely held conventional wisdom of economists. While it is well-known that any allocation mechanism has first-order distributional impacts ex-post, the broad interpretation of Coase (1960) suggests that there are no efficiency impacts of the allocation method because frictionless exchange always arrives at the same outcome. We agree with this interpretation, but rather than focusing on the implications of allocation *after* a market goes into effect, we focus in this paper on the effects anticipation confers *before* the market is implemented. We argue that when participants anticipate a future market for which rights will be grandfathered, this can induce a race for allocation which has largely gone unnoticed.

How could anticipation of a future allocation affect welfare even before a market goes into place? The basic intuition is most palpable with a pure grandfathering rule. When unregulated firms anticipate a future allocation in proportion to current use, they emit pollution or extract resources at an even more rapid rate than they would without any prospect of a future environmental market. This exacerbates preexisting market failures *before* the regulation comes into effect, which has implications for both efficiency and the distribution of wealth. Importantly, if the environmental market is targeting a *stock* problem (e.g. atmospheric carbon concentrations or biomass in a fishery), anticipatory behavior can drive down the stock level below the unregulated level before before the market is established. But even if the market addresses a pure *flow* problem (e.g. local air pollution or water quality) anticipation of grandfathering lowers welfare in the pre-market phase.

We set up a general model that can represent either an emissions externality or a resource extraction problem. We begin with a two-period model: Period 0 is a pre-market phase during which firms are unregulated but may anticipate a future market and, importantly, a corresponding initial allocation rule, and Period 1 is a market phase during which a regulator sets a welfare-maximizing cap, allocates rights, and then allows these rights to be traded. Within this setting we study the dynamic incentives that anticipation of any allocation rule engenders. We show that the expectation of future allocation rules can distort firms' incentives prior to the market being implemented. Indeed conventional grandfathering almost always leads to inferior environmental outcomes and lower Period-0 welfare than a completely unregulated state. In this sense, efficiency is not independent of the initial allocation of rights, which runs counter to modern interpretations of the Independence Axiom (Coase 1960). Our general framework allows us to consider a wide range of alternative allocation rules, including pure auctioning, equal allocation, among many others. One alternative, which we denote "Reverse-Grandfathering," is designed to *reverse* the incentives created by anticipated grandfathering. We show that Reverse-Grandfathering can realign incentives and, instead of exacerbating market failures prior to the market, in some cases can even replicate the first-best outcome *prior to* *the implementation of the environmental market.* Because Reverse-Grandfathering provides a positive allocation to incumbents, we show that it is generally more politically attractive than auctioning, though some firms may still prefer traditional grandfathering.

Establishing that anticipation affects welfare requires taking a somewhat broader perspective on how one defines the welfare effects of a policy change. We argue that a welfare analysis of a policy change should include any welfare impacts that occur in the unregulated period, *prior* to a market's establishment. As long as currently-unregulated firms anticipate a possible future allocation, pre-market behavior is impacted and hence welfare can be affected by the behavior of those firms. Moreover, if that behavior affects a pollution or resource stock - as is the case with fisheries, forests, and carbon - then welfare after the market is implemented may be affected.

In practice, some policymakers have worried about the anticipatory race for allocation, and have tried to find practical solutions to it. One proposed work-around is to establish a "look-back" period in the past that is used as the baseline for allocating future rights. While that approach may have worked in the early days of environmental markets, for several reasons we argue that it is unlikely to continue to work today. First, given the rapid adoption of environmental markets, we think it is next to impossible to find an unregulated resource where all users are completely unaware of the possibility of a future market allocation. In such a setting, identifying a sanitized look-back window will be challenging. Second, defining a historical look-back period requires that firm-level emissions or extraction have already been measured. In many cases, baseline measurements may not yet exist. Finally, we note anecdotally that policymakers often ignore the practical advice: in the establishment of the European Union's Emissions Trading Scheme (EU ETS), for example, the policy announcement came in 2001, and emissions permits would be allocated at the beginning of the market in 2005 based on emissions during the years 2001-2004, which may have induced firms to emit more during this interim period.

Our model is intentionally general, so as to capture diverse settings that are amenable to market-based approaches. The model accommodates cases where: (1) a flow externality, such as local air pollution, is generated by polluting firms and imposes costs on the current population, (2) a stock pollutant, such as carbon, accumulates from emissions and causes damage to current and future generations, (3) extraction of a natural resource, such as fisheries or groundwater, where one firm's extraction affects other firms' profits via a stock externality or congestion, and (4) environmental goods that affect welfare directly through individuals' valuation (e.g. biodiversity). All qualitative results can be demonstrated with a relatively simple two-period model.

To illustrate the mechanics of anticipation of a market, and to show order-of-magnitude effects, we develop a structural simulation of a hypothetical environmental market for fishing rights on the high seas. To parameterize the model, we employ high-frequency satellite tracking data from 4,898 unique fishing firms who target tuna, sharks, and other pelagic species. In that example we find that anticipation of a future grandfathering rule substantially lowers both welfare and fish stocks relative to the complete no-regulation counterfactual; the tragedy of the commons is much worse with the anticipation of a future market than in the complete absence of regulation. We then derive the welfare-maximizing allocation rule, and show how this substantially improves welfare and resource stocks.

The simulation also allows us to illustrate the critical role of the dynamic impacts of anticipation in a stock problem, as the anticipation of grandfathering drives down the resource stock. Because the environmental market period begins with a lower resource stock level, it takes years for the stock to recover to the *unregulated equilibrium* stock level and then rebuild to the optimal stock level. In contrast, if firms anticipate a Reverse-Grandfathering allocation rule, the overfished resource stock begins rebuilding prior to the start of the environmental market.

In the next section we review the use of markets to regulate environmental goods and natural resources, and we discuss settings where our model is likely to apply (i.e. where anticipated allocation rules may affect incentives). Following that background, we introduce a simple two-period model to illustrate how the anticipated allocation rule impacts firms' incentives prior to the establishment of an environmental market. Finally, we illustrate the role of anticipated allocation rules with a structural model of a hypothetical, but plausible, property rights system to regulate commercial fishing on the world's high seas.

2 Background

2.1 Allocation Rules Past and Present

Policymakers and regulators must determine an initial allocation of rights in a variety of settings. Our focus is on environmental markets, where a market for emissions or extraction is developed to cost effectively internalize an externality, but the problem of initially allocating property rights is much broader. Table 1 provides examples of the initial allocation of rights in a range of economic sectors. Examples include markets for carbon emissions (EU ETS; California's AB-32), the Acid Rain Program SO_2 Trading Program, the RECLAIM NO_x market in the Los Angeles Basin, and Individual Transferable Quotas in fisheries. Other examples of new markets requiring the allocation of property rights include newly-privatized firms granted to workers in post-Soviet Russia (Shleifer 1994, Shleifer and Treisman 2005); taxi medallions (Wyman 2013); land titling (Galiani and Schargrodsky 2010); and rights to orbits in outer space (Rao et al. 2020).[4] While the general tendency has been to grant rights based on historical access or use (Libecap 2007), examples also exist where rights are auctioned, divvied up equally, or distributed according to other formulae.

Our contribution is most closely related to the scholarship on allocation, equity, and efficiency of environmental markets, where the seminal paper is Coase (1960). While that paper has received diverse interpretations, a principle conclusion is that, under a set of assumptions (most importantly, the absence of transaction costs), the

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[4] In other settings the state may take actions to claim rights based on established use, such as China's recent claims in the South China Sea (Fravel 2011) or Russian claims of Arctic resources (Borgerson 2008).

Table 1: Examples of Allocation Rules

Allocated Right	**Description**	**Citation**
Carbon Emissions	European Union Emissions Trading Scheme (EU ETS); existing sources typically grandfathered in Phase I	Woerdman et al. (2009), Rode (2021)
Marine Fisheries	"Catch shares" granted as a share of overall harvest; typically grandfathered.	Lynham (2014)
SO_2 Emissions	Acid Rain Program, Title IV of the 1990 Clean Air Act (CAA) Amendments; existing firms initially grandfathered	Schmalensee and Stavins (2013)
NO_x Emissions	Regional Clean Air Incentives Market (RECLAIM) in South Coast of California; grandfathered	Fowlie and Perloff (2013)
Groundwater Rights	Adjudication in California; rights grandfathered.	Ayres et al. (2021)
In-stream Water Rights	Murray-Darling Basin, Australia; rights typically grandfathered based on historical use.	Rafey (2019)
Land Titling	Rights granted to users in Argentina.	Galiani and Schargrodsky (2010)
Land Rights	Settlement in American West generated a "race"; rights given to squatters under "Policy of Preemption."	Anderson and Hill (1975); Kanazawa (1996)
Mineral Rights	Leases on public lands and "unitization"	Wiggins and Libecap (1985)
Taxi Medallions	Used to restrict eligible cabs. New York City grandfathered rights to existing cabs in 1937.	Wyman (2013)
Spectrum Rights	Rights to transmit signals over specific bands of the electromagnetic spectrum.	Milgrom (2000, Weyl and Zhang (2020)
Satellite Orbits	Rights to orbits are not currently assigned.	Rao et al. (2020)
Privatization Post-USSR	State-owned enterprises privatized; workers granted shares.	Shleifer (1994)
Maritime Rights	Islands in South China Sea; Russia claiming rights in Arctic	Fravel (2011); Borgerson (2008)
Tobacco Production Quota	Transferable quota, grandfathered.	Rucker et al. (1995)
Carbon Offsets	Establishing baseline for offsets under Clean Development Mechanism.	Van Benthem and Kerr (2013)

allocation of rights will have no bearing on the efficiency of a market.[5] The argument is that the subsequent trading of rights will achieve allocative efficiency, regardless of the initial allocation of rights, because the ability to trade will move the rights to high-value users. This theoretical argument, which focuses entirely on behavior after the market is implemented, has received some recent empirical support by Fowlie and Perloff (2013), who leverage the variation in compliance periods by firms in the RECLAIM cap-and-trade market to identify the effect of the allocation on firm behavior. Several papers have focused on the functional role of different kinds of *transaction costs* (Stavins 1995) and have uncovered other settings in which the allocation of rights affects efficiency (see Leibbrandt and Lynham (2018) regarding perceived fairness of allocation, Hahn (1984) regarding imperfect competition, and Fowlie et al. (2016) regarding entry and exit dynamics). Anderson et al. (2011) directly compare grandfathering and auctioning of catch shares for fisheries. In their model rents are endogenous and arise due to research and development, and auctions dampen investment incentives when there are capital market imperfections. Harstad and Eskeland (2010) study the dynamic allocation of permits and rent-seeking in a permit market, and Meng (2017) uses anticipation of grandfathered carbon rights to estimate marginal abatement costs of regulated firms.[6] All of these papers focus on

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[5] Of course, one interpretation of Coase (1960) is that the time and frictions involved in implementing a market are, themselves, transaction costs. Viewed in this way, our finding that the allocation rule affects ex-ante market efficiency is completely consistent with Coase. According to this line of thinking, all environmental markets contain substantial transaction costs (the time to set up and implement the market) and therefore the finding that allocation affects efficiency does not contradict Coase, who clearly reasoned that transaction costs are nearly-ubiquitous.

[6] Li (2018) studies outcomes of the allocation of car licenses in Beijing and Shanghai, which utilize non-transferable permits and lotteries, respectively. He finds that the ex-post outcomes vary based on the allocation mechanism, but the non-transferability of licenses leads to different compositions of the fleet as well as environmental and welfare outcomes.

welfare and the efficiency of a market after it has been implemented. In contrast, we focus on how anticipation of a future market affects behavior and welfare *before the market is established*.

A rich literature emphasizes the importance of property rights, including the political economy of rights-based management systems. Following Coase (1960), Demsetz (1964) argued that firm owners operating under open access would recognize the potential gains of rights-based management and lobby for institutional changes. This optimistic view was challenged by Libecap (1989), who raised the importance of political actors in the establishment of rights-based environmental management. He also highlights challenges of environmental markets, including political economy issues that we later consider. Among the other critical points he raises, a small number of losers could affect the political viability of such a transition, following the tradition of Olson (2009). In the context of natural resources, Grainger and Costello (2015) highlight the importance of inframarginal rents under regulated open access as a justification for grandfathering of harvest rights when an environmental market is introduced.

A small but important literature uses the ideas in Coase to explore the race to acquire rights before they are allocated. There are several important papers regarding rent-seeking (Krueger 1974).[7] Nash (2009) describes the potential for strategic rent-seeking behavior in the context of environmental and resource regulation, including grandfathering in emissions trading schemes and rights-based management of natural resources. Other examples include the race for land claims in the settlement of

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[7] In settings with weak institutions and property rights, rent-seeking for valuable common pool resources can lead to the natural resource curse (e.g. (Sachs and Warner 2001) or (Torvik 2002).

the American West (Anderson and Hill 1975). Allen and Leonard (2019) liken the homestead "rationing by racing" to Yoram Barzel's "rationing by waiting" (Barzel 1974).[8] Allen and Leonard (2019) focus empirically on the determinants of the speed of the race; they find that investments in speed (to claim a parcel of land before someone else does) can dissipate potential rents, in a manner similar to rationing by waiting. Similarly, the Policy of Preemption (1830) resulted in a grandfathering rule that shifted away from auctioning land to an allocation of some property rights to land to squatters (Kanazawa 1996). Taxi medallions are another salient example, where current cab-owners in New York City lobbied for a policy to restrict entry; this ultimately created valuable transferable licenses (Wyman 2013).[9] Instead of spending scarce resources to race for ownership rights, Clark et al. (2005) and Clark et al. (2007) explore the possibility of spending scarce resources in anticipation of the government buying-out physical capital. In these papers, a fishery regulator is buying fishing vessels to reduce fishing pressure on over-exploited stocks. When current fishers anticipate such a buyout, they may build up physical capital, leading to several inefficiencies. Our paper includes the anticipatory effects described above, but we focus not only on policy change, but also the role of the allocation mechanism in affecting efficiency. Perhaps most importantly, we are able to derive an optimal allocation rule, a unique allocation formula that maximizes intertemporal welfare.

Anticipatory behavioral responses play an important role elsewhere in the liter-

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[8] Empirical applications include Deacon and Sonstelie (1985) and Frech III and Lee (1987).

[9] The Haas Act (1937) limited the number of taxis licensed at the time of passage and granted transferable licenses to grandfathered vehicle owners (Wyman 2013). §N.Y.C., N.Y., ORDINANCES, in Proceedings of the Board of Aldermen and Municipal Assembly of the City of New York From January 4, to June 29, 1937, vol. 1545 (Mar. 1, 1937).

ature related to the introduction of environmental regulations. The green paradox literature, beginning with Sinn (2008), has a motivation similar to ours, where the announcement of a future environmental policy can have consequences for current behavior. The canonical example is an announcement of a future carbon tax or other climate policy, which could plausibly lead to ramped-up extraction and use of fossil fuels in advance of policy implementation. Other poignant examples of preemptive behavior in advance of policy implementation include destroying endangered species habitat in advance of a species' listing (List et al. 2006); rapid increase in firearm purchases in advance of gun control legislation (Levine and McKnight 2017); an increase in the release of CFCs in anticipation of the Montreal Protocol (Auffhammer et al. 2005); and a more-than-doubling of fishing pressure in an area announced as a future marine reserve (McDermott et al. 2019). Thus, this literature focuses on how a future policy that imposes costs on an economic sector will affect behavior.

There are many other important settings where expected regulations or the provision of information can change behavior. Prominent examples include the impact of information about electricity prices on demand elasticities (Wolak 2011, Jessoe and Rapson 2014); the effect of information provision regarding nonlinearities in the tax code on labor supply (Chetty and Saez 2013); the impact of attribute-based regulations on firm behavior (Ito and Sallee 2018); or adaptation to expected future climate (Dell et al. 2014). Furthermore, transition effects of tax policy have long been discussed in the legal literature (Kaplow 1986, Bradford 1995, Kaplow 2006), and issues of fairness naturally arise in the context of emissions taxation (Sallee 2019). Finally, one of the central concerns about international climate policy is climate justice; the countries who may suffer disproportionately under climate change are often different than the largest historical emitters. In any emissions trading program, questions of fairness arise in the grandfathering of permits (Posner and Weisbach 2010).

The European Union Emissions Trading System (EU ETS) has been widely studied, and several contributions focus on the allocation of rights. For example, Branger et al. (2015) study the impact of "activity level thresholds," which define the minimum output required to qualify for free allocations. These thresholds were intended to reduce over-allocation of free allowances to low-activity installations, but in practice Branger et al. (2015) find that the thresholds induced firms to strategically increase output. They argue that a linear output-based allocation without thresholds would have led to a larger emissions reduction. The allocations in the EU ETS across countries is complicated by negotiations between countries and the allocation rules within each country. Rode (2021) focuses on the initial allocation of permits in the United Kingdom, which was subject to an appeal process; firms with financial ties to members of the House of Commons were able to increase their relative shares, on average. Neuhoff et al. (2006) use simulations of alternative allocation rules to study the distortionary impacts of the race for allocation. They consider alternative allocation rules, including how to allocate permits to new entrants, and they argue that a uniform benchmark creates the fewest distortions for both new entrants and incumbents. Their simulations focus on a suite of policies in place in National Allocation Plans (NAPs); as such they do not consider other allocation rules, such as auctions or the reverse-grandfathering rule that we introduce in this paper.

Finally, our paper is related to a growing literature on climate policy and leakage. When one region establishes a pollution market, but another region remains unregulated, a pollution reduction in the regulated region may be (partially) offset by subsequent pollution increases in the unregulated region. A potential solution is to allocate free pollution permits on the basis of output (e.g. Böhringer and Lange (2005) and Demailly and Quirion (2006)), thereby neutralizing the channel through which leakage can occur.[10] Rather than allocating based on emissions or output, another possibility is to allocate based on benchmarks.[11] Important contributions have been made by Fowlie (2009), Fischer (2001), Fischer and Fox (2007), Meunier et al. (2014), and others.[12] In that literature, once a market is implemented, firms' pollution decisions in period t depend on how they expect permits to be re-allocated in period $t+1$, and the leakage channel requires a market with competitive advantage and trade across regulated and unregulated regions. While similar in spirit to these contributions, the motivation for our allocation rule has nothing to do with leakage - rights are allocated as a first step in establishing an environmental market. Thus, our model and results will not require any assumptions about trade, comparative advantage, or leakage. We regard our paper as complementary to this literature in that we identify and study a different channel through which allocation affects firm incentives and social welfare.

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[10] See Mackenzie et al. (2008) for an extension considering allocations based on emissions as well as output. Border tax adjustments (e.g. Böhringer et al. (2018)) may be a more effective, though possibly politically untenable, solution.

[11] The extent of direct and indirect emissions for output may affect firm incentives under benchmark-based allocations (Zipperer et al. 2017).

[12] Concerns about distortions in agricultural subsidies has led to a "decoupling," basing subsidies not just on output but also on acreage (O'Neill and Hanrahan 2012).

2.2 Allocations in Environmental Markets

Environmental markets are used to cost-effectively address externalities, and they have been used in a wide variety of settings, such as emissions (Montgomery 1972) and natural resource extraction rights to overcome the tragedy of the commons (Hardin 1968). For example, individual transferable quotas (in fisheries) and groundwater extraction rights have been shown theoretically and empirically to slow the pace of extraction, allow resource stocks to rebuild, and generally improve extractors' welfare (Costello et al. 2008). Another poignant example is the Acid Rain Program, which established tradable permits for SO_2 emissions in the United States and led to a substantial decrease in emissions (Schmalensee and Stavins 2013). In this section we provide a brief review of the reach and use of environmental markets, with an emphasis on allocation mechanisms. We focus on the introduction of environmental markets by a regulatory authority and abstract away from endogenous establishment of property rights in common pool resource settings, as in Hafer (2006) or Grossman (2001).

In principal, extraction rights for natural resources could be auctioned, divided equally among all resource users, allocated in proportion to historical use (i.e. grandfathered), or freely distributed according to some other formula. In practice, however, almost all natural resource markets allocate rights in proportion to historical harvest (Lynham 2014, Costello and Grainger 2018).[13]

Just as with natural resource extraction rights, the initial allocation in emis-

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[13] Grandfathering is widely used, and it has a number of intuitively appealing properties because, loosely speaking, it starts the environmental market off where the previous regime left off and confers rights to the most active incumbents.

sions markets determines how an overall pollution cap is initially distributed across emitting sources. While this allocation could be done any number of ways, in practice many emissions markets allocate rights by grandfathering. Prominent examples include the SO_2 market created under Title IV of the 1990 Clean Air Act Amendments (Schmalensee and Stavins 2013), the Regional Clean Air Incentives Market (RECLAIM) to regulate NO_x in the South Coast Air Quality Management District of California (Fowlie and Perloff 2013), and the first phase of the European Union Emissions Trading Scheme (Ellerman and Buchner 2008). Cramton and Kerr (2002) argue that auctioning is preferable due to a number of factors, including incentives for innovation and avoiding political decisions associated with allocation rules. In contrast, Joskow and Schmalensee (1998) argue that political economy may require concessions such as free allocation, as in the Acid Rain Program's SO_2 trading scheme.

Offsets and ecosystem services provide another salient example to which our theory pertains. Carbon offsets are credits for emissions reductions that can be certified and subsequently bought by consumers (e.g. Kotchen (2009)) or firms in emissions markets through the Clean Development Mechanism (e.g. Wara and Victor (2008)). In a market for carbon offsets, a baseline must be established to determine which activities are eligible to generate credits that are additional to the counterfactual scenario. A common concern regarding offsets is that firms may manipulate baseline trends in order to sell more offset credits upon establishment of the market. This could arise through increasing deforestation rates or reducing the rate of adoption of renewable energy technologies—in either case, a firm can increase its offset credit allocation by changing its baseline behavior. Van Benthem and Kerr (2013) study the establishment of baselines and find that increasing the baseline scale reduces both adverse selection and transfers; their insight helps motivate our analysis.

Regardless of the setting, environmental markets have several common characteristics that we introduce in the next section. We note that an effective environmental market cannot be established without institutions and data. Prior to establishing the market, property rights must be established, and institutions for the market must be designed. This includes establishing the necessary legal framework, trading infrastructure, enabling monitoring and enforcement, gathering baseline data, building political coalitions, and so on. Indeed, in some cases there may not even be adequate monitoring of firms to establish a baseline of historical activity. For example, prior to carbon emissions regulations, CO_2 emissions may not be universally measured, or in the case of commercial fisheries, harvest may not be tracked in all jurisdictions. After a baseline is established and property rights have been defined, the regulator must choose an allocation method and distribute rights to individuals or firms. Finally, after the initial allocation has taken place, individuals are allowed to buy and sell rights in the environmental market that we assume to operates without frictions.

3 Baseline Model

Here we derive a simple model of environmental markets, allocation, and anticipation that can be applied to a range of environmental and resource problems. We begin by assuming that firms make *emissions* decisions, taking ambient environmental quality

Q as given. Aggregate emissions from the entire industry ultimately affects the equilibrium level of Q. While we focus on emissions (such as carbon) for illustrative purposes, the model is designed to also apply to problems of resource extraction (such as water). There are N firms, and firm i chooses emissions e_i to maximize profit $\pi(e_i, Q; \gamma_i)$, where we will use the shorthand $\pi_i(.)$ for convenience. Profit for firm i depends directly on i's emissions, and it may also depend on aggregate ambient environmental quality,[14] which is itself a function of aggregate emissions ($e \equiv \sum_j e_j$). Firms are heterogeneous such that i's profit also depends on firm i's "productivity", γ_i, where higher productivity corresponds to higher profit (e.g. via lower costs).[15]

We assume that firms ignore their effect on environmental quality, so holding environmental quality Q fixed, we assume $\pi_i(e_i)$ is concave and single-peaked in e_i, so $\pi_i' > 0$ and $\pi_i'' < 0$. We assume that the environmental quality function $Q(e)$ captures natural biological, physical, and chemical processes and that Q is decreasing in aggregate emissions ($\frac{\partial Q}{\partial e} < 0$). We also assume environmental quality has a non-negative effect on profit ($\frac{\partial \pi_i}{\partial Q} \geq 0$). Finally, productivity increases profitability ($\frac{\partial \pi_i}{\partial \gamma_i} > 0$) and has an increasing effect on marginal profit ($\frac{\partial^2 \pi_i}{\partial e_i \partial \gamma_i} > 0$). The latter assumption ensures that high-productivity firms find it privately optimal to emit more than low-productivity firms. Notice that replacing the word "emissions" with the word "extraction" (of a natural resource such as water) delivers the exact same

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[14] This could be the case if environmental quality is a productive amenity, as in Roback (1982), or in a resource setting where environmental quality could be the resource stock, where extraction costs vary with the stock level.

[15] Lyubich et al. (2018) also use productivity as a measure of firm-level heterogeneity in an environmental setting. In that case, productivity is defined as output per unit of emissions. We remain agnostic about the specific functional form of productivity, and instead rely on the properties of π_i, as described below.

interpretation.

The first order condition for firm i's profit maximization (for an interior solution) is:

$$\frac{\partial \pi_i(e_i, Q; \gamma_i)}{\partial e_i} = 0 \tag{1}$$

Let the solution to this be denoted $\bar{e}_i(Q)$; if firm i observes aggregate environmental quality Q, it will find it privately-optimal to emit $\bar{e}_i(Q)$. Summing across all firms j implies that aggregate emissions at environmental quality Q is $\bar{e}(Q) \equiv \sum_j \bar{e}_j(Q)$. Emissions affect environmental quality, but nature determines $Q(e)$; that is, now environmental quality depends on aggregate emissions, so the economy-environment equilibrium level of emissions and environmental quality is determined by the intersection of $\bar{e}(Q)$ (from firms' decisions) and $Q(e)$ (from nature).

3.1 Designing an Environmental Market

The environmental market designer seeks to maximize social welfare, not just the short-run profits of firms. Suppose the social benefit from environmental quality is given by $B(Q)$, where $B' > 0$ and $B'' < 0$. The objective function of the social planner is:

$$\max_{\{e_1, e_2, \ldots\}} \sum_i \pi_i(e_i, Q(e); \gamma_i) + B(Q(e)). \tag{2}$$

The first order condition that determines firm i's optimal emissions from the perspective of the social planner is:

$$\frac{\partial \pi_i}{\partial e_i} + \sum_j \frac{\partial \pi_j}{\partial Q}\frac{\partial Q}{\partial e_i} + \frac{\partial B}{\partial Q}\frac{\partial Q}{\partial e_i} = 0, \tag{3}$$

which recognizes firm i's effect on environmental quality. Collecting terms, this first order condition can be rewritten:

$$\frac{\partial \pi_i}{\partial e_i} = -\frac{\partial Q}{\partial e_i}\left[\sum_j \frac{\partial \pi_j}{\partial Q} + \frac{\partial B}{\partial Q}\right]. \tag{4}$$

The left-hand side of equation 4 is the private marginal benefit to firm i of one more unit of emissions. The right-hand side is the social marginal cost of an additional unit of emissions from firm i. There are two components of this social marginal cost. The first term shows the effect of an additional unit of emissions from i on the profit of the industry. Even though this cost is internal to the industry, it is not internalized by firm i because firm i ignores the effect of her emissions on environmental quality.[16] The second term is the effect of an additional unit of emissions from firm i on the benefit society receives from environmental quality. These benefits are assumed to be exogenous to the industry. Finally, because a unit of emissions from firm i and j has the same effect on environmental quality ($\frac{\partial Q}{\partial e_i} = \frac{\partial Q}{\partial e_j}$), the right hand side is identical for all i.

Observation 1. *Under this model, the private marginal benefit differs by firm but the social marginal cost is identical across firms. This implies that a constant emissions tax (per unit of e), or equivalently, an emissions cap with frictionless trade, can solve the social planner's problem*

Equation 4 reveals two kinds of externalities in our model. The first is the externality firm i's emissions impose on other firms: One farmer's extraction from an

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[16] Much like a single driver ignores her effect on congestion or a single fisherman ignores his effect on the fish stock.

aquifer affects other farmers in the area via lower groundwater levels. The second is the externality firm i's emissions impose on the rest of society: One farmer's extraction of water reduces river rafting opportunities for non-farmers. Observation 1 simply states that an appropriately designed tax or cap-and-trade program will incentivize all firms to adhere to Equation 4. For example, suppose a charge τ is imposed for each unit of emissions. Each firm i would choose emissions such that her marginal benefit from emissions equals the tax: $\frac{\partial \pi_i}{\partial e_i} = \tau$. For any τ, this would imply a given level of aggregate emissions, and thus, a corresponding level of environmental quality, Q. The socially optimal emissions tax is the one that gives rise to a level of environmental quality such that Equation 4 is satisfied for all i. Let the respective socially-optimal emissions charge, emissions for firm i, and environmental quality be given by τ^*, e_i^*, and Q^*.

Because the focus of this paper is on the allocation of rights in an environmental market, we will focus on a market design under which emissions rights are allocated across firms. To achieve the socially optimal level of emissions from each firm i, the social-welfare-maximizing market designer allocates $\sum_i e_i^*$ emissions rights and allows them to be traded. Conveniently, it is straightforward to see that the resulting market clearing trading price is, by construction, τ^*.[17] Alternatively, the market designer could auction all emissions permits (so they allocate nothing to firms). The resulting equilibrium auction price in this model is, again, τ^*. In fact, any initial allocation of rights could, in principle, be used. As long as frictionless trading is then allowed, firms buy and sell rights such that the equilibrium price satisfies $\frac{\partial \pi_i}{\partial e_i} = \tau^*$.

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[17] We note here that we focus only on equilibrium permit prices, acknowledging that alternative allocations of rights may start the environmental market far from the equilibrium allocation.

Observation 2. *Because post-trading emissions are independent of the initial allocation of rights, these trades are simply transfers from a welfare standpoint. Thus, in the environmental market described above, the allocation of rights has no effect on efficiency (but does affect firm-level profits).*

This observation, which applies only *after* the market is implemented, is known as the Independence Axiom, attributed to Coase (1960). We now build on this model to understand how anticipated allocation rules affect efficiency in the time period before the market goes into place.

4 Two-Period Model with Anticipation

If no market exists and the industry is completely unregulated, then firm i chooses emissions according to Equation 1 (denoted $\bar{e}_i$), thus ignoring both kinds of externalities identified above. It is easy to see that unregulated emissions are larger than socially optimal emissions ($\bar{e}_i > e_i^*$), and consequently that unregulated environmental quality is lower than socially optimal environmental quality ($\bar{Q} < Q^*$). The premise of this paper is that if firms *anticipate* a future environmental market, or, more precisely, if firms *anticipate an allocation rule* for a future environmental market, then this anticipation can significantly affect pre-market behavior and welfare.

To analyze this problem, we extend the model to two periods. Each period can be thought of as a duration of time (such as a decade), and for simplicity we assume that the economy-environment equilibrium is reached in each period.[18] Period-0 is

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[18] In Section 7 we develop a fully-dynamic version of this model, but the main conclusions remain unchanged, so for expositional clarity, we adhere to the two-period model here.

the pre-market period under which firms are not bound by any regulation and are free to chose any emissions level. In period-0, firms anticipate the possibility of a market being implemented in period-1. We assume that if a market is implemented at the beginning of period-1, the socially-optimal cap is set, an allocation of rights occurs, and frictionless trade is allowed across firms. Under those assumptions, since the socially optimal cap has been set, firms can buy or sell emissions rights at price τ^*, derived above, regardless of the initial allocation of rights. Thus, a firm's free allocation of e_i emissions rights have a market value of $e_i\tau^*$, so we can think of the allocation as either the physical quantity of emissions rights (e_i) or the value of those rights ($e_i\tau^*$); we henceforth consider the latter, so the allocation is in monetary units.

While period-0 is completely unregulated, a market may be introduced in period-1. It is also possible, however, that the market never materializes. We consider both cases below.

Case 1: A Market is Introduced in Period-1

Working backwards, we solve for period-1 emissions of firm i (adding time subscripts for $t = 0, 1$). If the market materializes in period-1, firm i solves:

$$\max_{e_{i1}} \pi_i(e_{i1}, Q_1(e_1)) + \underbrace{A(e_{i0}) - \tau^* e_{i1}}_{\text{Net Allocation}} \tag{5}$$

The term $A(e_{i0})$ is the free allocation of rights, which occurs in period-1, and may depend on historical emissions, e_{i0}. The term $\tau^* e_{i1}$ is the total cost (more precisely, the opportunity cost) of acquiring rights in period-1 at trading price τ^*. So the expression $A(e_{i0}) - \tau^* e_{i1}$ is firm-i's net allocation of rights in period-1. Notice that if the firm is allocated exactly the same number of permits (or market value of permits) as it chooses to emit in period-1, then this term is zero. Instead, if firm i is allocated more rights than it chooses to use, then the surplus is sold (at price τ^*) and the net allocation is positive. And if it is allocated fewer rights than it wishes to use, then permits must be purchased (at price τ^*), and the net allocation is negative. The special case of zero free allocation implies that all rights must be purchased at price τ^*, which is precisely the case for a pure auction.

The first order condition for firm i in period-1 is $\frac{\partial \pi_{i1}(e_{i1}, Q_1)}{\partial e_{i1}} = \tau^*$, which implies that firm i's emissions equate its marginal profit with the socially-optimal trading price of permits. This confirms the social-optimality of the equilibrium cap-and-trade trading price (τ^*). So in this case where the market materializes, firm i earns period-1 profit of:

$$\pi_i(e_{i1}^*, Q_1(e_1^*)) + A(e_{i0}) - \tau^* e_{i1}^* \tag{6}$$

Case 2: No Market is Introduced in Period-1

Instead, if the market fails to materialize in period-1, then no allocation of rights will be necessary, so firm i solves:

$$\max_{e_{i1}} \pi_i(e_{i1}, Q_1(e_1)) \tag{7}$$

which implies $\frac{\partial \pi_{i1}(e_{i1}, Q_1(e_1))}{\partial e_{i1}} = 0$. Here, firm i chooses emissions to such that marginal profit equals zero. Thus, if the market fails to materialize, firm i earns period-1 profit of:

$$\pi_i(\bar{e}_{i1}, Q_1(\bar{e}_1)) \tag{8}$$

where $\bar{e}_{i1}$ was derived in Equation 1. We will invoke these findings as we step back to period-0.

Anticipation of a Future Market

In period-0, firms anticipate the possibility of a future market in which rights will be allocated according to the rule $A(e_{i0})$. Because the allocation will occur in the future, we include a discount factor (δ). And to account for uncertainty over the market arising, let ω be the probability that the market materializes, and $(1-\omega)$ be the probability that the no-regulation incentives will prevail in period-1. Under this two period model, firm i chooses emissions in period-0 (denoted e_{i0}) to solve:

$$\max_{e_{i0}} \underbrace{\pi_i(e_{i0}, Q_0(e_0))}_{\text{Pre-market}} + \delta\omega \left[\underbrace{\pi_i(e^*_{i1}, Q_1(e^*_1)) + A(e_{i0}) - \tau^* e^*_{i1}}_{\text{Environmental market}} \right] + \delta(1-\omega) \underbrace{\pi_i(\bar{e}_{i1}, Q_1(\bar{e}_1))}_{\text{No market}} \tag{9}$$

The first term is the profit to firm i from emissions in the pre-market (i.e. unregulated) period. The second underbraced term is the period-1 profit to firm i in the event that the environmental market materializes, drawn from Equation 6. It is discounted by δ and weighted by the probability that the market materializes (ω). The third underbraced term is the period-1 profit to firm i in the event that the market fails to materialize, drawn from Equation 8. It is discounted and weighted by the relevant probability.

The period-0 first order condition is:

$$\frac{\partial \pi_i}{\partial e_{i0}} = -\delta \omega A'(e_{i0}) \tag{10}$$

That is, firm i's optimal period-0 emissions level is now a function of the anticipated market allocation. Recalling that π_i is concave in e_i, this expression suggests that if the allocation rewards extraction (so higher period-0 emissions are rewarded with a larger free allocation, $A' > 0$), then period-0 emissions will be even larger than in the completely unregulated setting. In other words, if firms anticipate a traditionally-grandfathered allocation, emissions are higher than under the no-regulation counterfactual setting.

4.1 The Role of the Anticipated Allocation

Moving forward, we specify a general linear class of allocation rules $A(e_i)$. In practice, the allocation can be determined in many different ways, and may or may not depend on i's emissions during period-0. By far the most common real-world allocation rule is Grandfathering, where rights are allocated in direct proportion to the firm's period-0 emissions. Other common approaches include Equal Allocation (where all firms are allocated the same rights), a mixed approach such that a fraction of rights are allocated equally and the remainder are grandfathered, or Auctioning (where no free allocation occurs and firms must buy all rights at auction). We propose and analyze a general form for $A(e_i)$ that nests all of these approaches as special cases, but also allows us to examine a range of other allocation approaches. We assume that firm

i's free allocation at the beginning of the environmental market is given by:

$$A(e_{i0}) = F + \theta e_{i0}. \tag{11}$$

Notice that this allocation rule covers the cases of traditional Grandfathering ($F = 0$ and $\theta > 0$), Equal Allocation ($F > 0$ and $\theta = 0$), Mixed ($F > 0$ and $\theta > 0$), and complete Auctioning ($F = 0$ and $\theta = 0$).

In practice, the aggregate allocation of rights often equals the aggregate cap on emissions. For example, if the the sector-wide target emissions cap is 10 tons, the sum of permits allocated in the market will equal 10 tons; alternatively, if the socially-optimal extraction from an aquifer is 1,000 acre-feet per year, then the aggregate allocation will typically be 1,000 acre-feet. However, it is also possible that the allocation could be larger than, or smaller than, the desired cap. If the free allocation exceeds the desired cap by Δ, then Δ rights would be bought back by the regulatory agency, presumably at total cost $\Delta\tau^*$.[19] If the free allocation is less than the desired cap by Δ, then Δ rights would be auctioned to users, thus generating auction revenue of $\Delta\tau^*$, again assuming the equilibrium price corresponding to the socially-optimal cap. We allow for all of these possibilities (an over-, under-, or revenue neutral allocation of rights).

If firm i anticipates a future allocation rule given by Equation 11, then it will choose period-0 emissions such that $\frac{\partial \pi_i}{\partial e_{i0}} = -\delta\omega\theta$. Let that level of emissions be denoted $\hat{e}_{i0}(Q)$, noting the dependence on aggregate environmental quality. Total

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[19] This occurred in New Zealand when fishing rights were over-allocated to incumbent fishermen, and were subsequently bought back. See Grainger and Costello (2014).

differentiation leads to the following result:

Proposition 1. *For any Q,*

(a) if $\theta > 0$, firm i's period-0 emissions are larger than under the base case of no regulation (and no anticipated market);

(b) the larger is θ, the larger are i's period-0 emissions.

Proof. Without anticipation, firm i's period-0 emissions solve $\frac{\partial \pi_i}{\partial e_{i0}} = 0$. With anticipation of the allocation rule $F + \theta e_{i0}$, firm i's period-0 emissions solve $\frac{\partial \pi_i}{\partial e_{i0}} = -\delta\omega\theta$. Noting that $\delta\omega > 0$, the concavity of $\pi_i(e_{i0})$ ensures the result. □

Proposition 1 reveals that before a market goes into place, if firms anticipate a future market in which rights will be Grandfathered (so $\theta > 0$), their pre-market emissions will increase relative to what would have occurred without such anticipation.

5 Reverse-Grandfathering

Since the anticipation of Grandfathering (i.e. $\theta > 0$) creates a perverse incentive to increase emissions prior to the environmental market (Proposition 1), we now ask: Could the anticipation of an alternative allocation rule help correct the pre-market emissions externality? We find that the answer is yes. We use the term "Reverse-Grandfathering" to refer to any allocation rule for which $\theta < 0$. And for a specific Reverse-Grandfathering rule, we find that emissions are socially optimal, even in the complete absence of regulation, summarized as follows:

Proposition 2. *If firms anticipate a Reverse-Grandfathering allocation rule where* $\theta = -\frac{\tau^*}{\delta\omega}$*, then their unregulated emissions exactly equal the socially optimal emissions.*

Proof. Any Reverse-Grandfathering rule imposes a present value *cost* per unit of period-0 emissions. From above, we know that once the market is put in place, the optimal shadow price is τ^* per unit of emissions. To achieve the same expected present value incentives in period-0, we set $\theta = -\frac{\tau^*}{\delta\omega}$. By doing so, the period-0 first order condition for firm i becomes $\frac{\partial \pi_i}{\partial e_{i0}} = \delta\omega(\tau^*/\delta\omega) = \tau^*$, which delivers precisely the social planner's desired level of emissions. $\square$

Proposition 2 is a powerful result. It shows that a regulator can induce socially-optimal behavior, even in the complete absence of regulation (i.e. in period-0), as long as firms anticipate a particular Reverse-Grandfathering allocation rule. The idea is that firms change their behavior before regulation occurs in order to secure a larger share of the future free allocation. While *any* Reverse-Grandfathering rule will reverse the incentives engendered by a Grandfathering rule, only the specific rule in which $\theta = -\frac{\tau^*}{\delta\omega}$ delivers precisely the socially optimal emissions incentives.

At first glance, Reverse-Grandfathering sounds like an ideal way to allocate all rights in environmental and resource markets. Even prior to any regulation, a regulator can incentivize firms to behave *as if* they are perfectly regulated by committing to (or signaling the possibility of) an allocation rule that rewards prudence rather than rewarding excessive emissions. In a stylized world, the case is closed and this seems to solve our problem. But we find that the very nature of the Reverse-Grandfathering allocation rule changes incentives for participation and entry, which could undermine its efficacy as a tool for reversing the tragedy of the commons. We consider these trade-offs in this section.

5.1 Participation

In period-0, firms are completely unregulated and are not obliged to undertake any emissions controls. However, if a market materializes in period-1, then firm i knows it will receive an allocation of $A(e_{i0})$. Here, we consider whether firms will *participate* in that free allocation, that is, whether they will accept the free allocation of rights at the beginning of the market.

Under traditional Grandfathering, it is intuitive that firms will always choose to accept the free allocation of rights, and we will prove that this is the case for any such allocation. However, under Reverse-Grandfathering, it is possible that some high emissions firms would receive a negative allocation (i.e. $F + \theta e_{i0} < 0$ because $\theta < 0$ for a Reverse-Grandfathering rule), in which case the firm may reject the free allocation of rights. If a firm rejects the free allocation of rights, then it must purchase all period-1 emissions rights at the market-clearing price, τ^*.

Definition 1. *A firm* **participates** *in the free allocation if it chooses, in period-0, to accept the free allocation in period-1, upon initiation of the market.*

How will firm i decide whether to participate? The key insight is that for any allocation rule, firm i knows in period-0 what her allocation will be if the market materializes in period-1. Once period-1 arrives, and the market allocations occur, the firm will accept the free allocation if and only if it is positive, i.e. if $A(e_{i0}) =$

$F + \theta e_{i0} > 0$. Knowing this, the firm must decide e_{i0} in period-0. The firm must compare two cases: If she participates, she chooses e_{i0} knowing that if the market materializes, she will accept the free allocation. If she defects, she chooses e_{i0} knowing that if the market materializes, she will reject the free allocation. Recalling that $\hat{e}_{i0}$ satisfies $\frac{\partial \pi_i}{\partial e_{i0}} = -\delta\gamma\theta$, taking environmental quality as given, firm i will participate so long as the following holds:

$$\underbrace{\pi_i(\hat{e}_{i0}, Q) + \delta\omega F + \delta\omega\theta\hat{e}_{i0}}_{\text{Participate}} > \underbrace{\pi_i(\bar{e}_{i0}, Q)}_{\text{Defect}}, \tag{12}$$

where $\bar{e}_{i0}$ is firm i's emissions in the absence of regulations and no anticipated future environmental market.

In other words, firm i *participates* in the free allocation if its expected profit from participating (with associated allocation and optimized emissions, $\hat{e}_{i0}$) exceeds its profit from not participating (with no free allocation and reverting to no-anticipation emissions, $\bar{e}_{i0}$), noting importantly that $\hat{e}_{i0} \neq \bar{e}_{i0}$.[20]

Interestingly, if a firm decides not to participate in the free allocation, then it chooses period-0 emissions according to the no-anticipation incentives (i.e. facing a marginal emissions price of 0). Instead, if it decides to participate, then it chooses period-0 emissions in a manner that accounts for the anticipated allocation parameter

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[20] Might firm i hedge the uncertainty about whether the market will materialize by choosing $\bar{e}_{i0}$ and then accepting the free allocation only if the market materializes? This kind of behavior can be ruled out as follows. Definitionally, we know that $\bar{e}_{i0}$ maximizes $\pi_i(e_{i0}, Q)$ and $\hat{e}_{i0}$ maximizes $\pi_i(e_{i0}, Q) + \delta\omega(F + \theta e_{i0})$. The latter definition ensures $\pi_i(\hat{e}_{i0}, Q) + \delta\omega(F + \theta\hat{e}_{i0}) > \pi_i(\bar{e}_{i0}, Q) + \delta\omega(F + \theta\bar{e}_{i0})$, so if the free allocation will eventually be accepted, $\hat{e}_{i0}$ is firm i's optimal emissions choice in period-0. Similarly if the free allocation will be rejected, then $\bar{e}_{i0}$ is firm i's optimal emissions choice in period-0.

θ. In other words, firm i's period-0 emissions are defined implicitly by:

$$e_{i0} \text{ given by } \begin{cases} \frac{\partial \pi_i}{\partial e_{i0}} = -\delta\omega\theta \text{ if } i \text{ Participates, denoted } \hat{e}_{i0} \\ \\ \frac{\partial \pi_i}{\partial e_{i0}} = 0 \text{ if } i \text{ Defects, denoted } \bar{e}_{i0} \end{cases} \tag{13}$$

Since π_i is concave in e_i, this implies that i's optimal emissions are lower under Participation than under Defection if and only if $\theta < 0$ (i.e. a Reverse-Grandfathering rule is used). Once again, if $\theta = -\frac{\tau^*}{\delta\omega}$, then the first equation mirrors the social planner's optimal solution.

What can we conclude about which firms will participate and which will defect? It can be shown, and the intuition quickly follows, that all firms rationally participate in any traditional Grandfathering rule, but that under Reverse-Grandfathering, some firms might defect. If any firms defect, they will be the highest-productivity firms. To build intuition, consider a high-productivity firm who, under participation, knows it will receive an allocation of exactly zero (so $F = -\theta\hat{e}_{i0}$). Such a firm will unambiguously defect because, by definition of optimality, $\pi_i(\bar{e}_{i0}) > \pi_i(\hat{e}_{i0})$. This same logic holds even for firms that, by participating, would receive a sufficiently small, but still positive, allocation.[21] That is, securing a positive allocation from participation is necessary, but not sufficient, for participation. Our key results regarding participation are summarized as follows:

Proposition 3. *(a) Under traditional Grandfathering ($F \geq 0$ and $\theta > 0$), all*

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[21] In other words, if the firm chose the participation level of emissions ($\hat{e}_{i0}$), it would receive a small but still positive allocation. By our argument above, such a firm would accept the free allocation in period-1. However, we can show that when this allocation is sufficiently small, the defection payoff is always larger, so such a firm would always defect.

firms participate in the free allocation, and thus choose emissions $\hat{e}_{i0}$ *in period-0.*

(b) *Under Reverse Grandfathering* ($F \geq 0$ *and* $\theta < 0$)*, sufficiently high-productivity firms will will reject the free allocation. These defecting firms choose period-0 emissions* $\bar{e}_{i0}$ *instead of* $\hat{e}_{i0}$*. Low-productivity firms will participate in the free allocation.*

(c) *Under the particular Reverse Grandfathering rule where* $\theta = -\frac{\tau^*}{\delta\omega}$*, if any firms reject the free allocation, then it is not possible for any allocation rule to replicate socially optimal period-0 emissions.*

Proof. For any allocation rule, the participation constraint is given by Equation 12 and the optimized emissions are characterized by Equation 13. Because $\pi_i(e_i, Q)$ is concave in e_i, $\hat{e}_{i0} < \bar{e}_{i0}$ if and only if $\theta < 0$. Define the "willingness to participate" as follows:

$$\Phi = \pi(\hat{e}_{i0}, Q; \gamma_i) + \delta\omega(F + \theta\hat{e}_{i0}) - \pi(\bar{e}_{i0}, Q; \gamma_i), \tag{14}$$

which is just the period-0 profit to i from Participation minus the period-0 profit to i from Defection. Firm i participates if and only if $\Phi > 0$. Taking the derivative with respect to γ_i, and invoking the envelope theorem gives:

$$\frac{d\Phi}{d\gamma_i} = \frac{\partial\pi(\hat{e}_{i0})}{\partial\gamma_i} - \frac{\partial\pi(\bar{e}_{i0})}{\partial\gamma_i} \tag{15}$$

Both terms on the right hand side are positive (from our assumption that $\frac{\partial\pi}{\partial\gamma} > 0$). We now invoke our assumption that $\frac{\partial^2\pi}{\partial e_i \partial\gamma_i} > 0$, which establishes that $\frac{\partial\pi(\hat{e}_{i0})}{\partial\gamma_i} > \frac{\partial\pi(\bar{e}_{i0})}{\partial\gamma_i}$

if and only if $\hat{e}_{i0} > \bar{e}_{i0}$.

To prove part (a), note that traditional Grandfathering implies $\theta > 0$, so $\hat{e}_{i0} > \bar{e}_{i0}$, which implies $\frac{\partial \pi(\hat{e}_{i0})}{\partial \gamma_i} > \frac{\partial \pi(\bar{e}_{i0})}{\partial \gamma_i}$, so $\frac{d\Phi}{d\gamma_i} > 0$. This proves that under traditional Grandfathering, high-productivity firms are the most amenable to Participation (and low-productivity firms are the least amenable to participation). Consider the lowest possible productivity firm, which chooses $\hat{e}_{i0} = 0$. Even this firm would participate, provided $F > 0$. Since higher productivity firms are even more amenable to participation, this confirms that all firms will participate under traditional Grandfathering.

To prove part (b), note that $\theta < 0$ under Reverse-Grandfathering, so $\frac{d\Phi}{d\gamma_i} < 0$, and the high-productivity firms are the least amenable to participation. To see that some (high-productivity) firms may defect, observe that for sufficiently small F, $\Phi < 0$ (a sufficient condition is $F + \theta \hat{e}_{i0} < 0$, recalling that $\theta < 0$). Because $\frac{d\Phi}{d\gamma_i} < 0$, if a firm i with γ_i defects, then all firms k with $\gamma_k > \gamma_i$ will also defect. And if a firm j with γ_j participates, then all firms l with $\gamma_l < \gamma_j$ will also participate.

To prove part (c), note that to achieve the socially-optimal period-0 emissions level, each firm i must choose emissions e_{i0} such that $\frac{\partial \pi_i}{\partial e_{i0}} = \tau^*$, which requires setting $\theta = -\frac{\tau^*}{\delta\omega}$, and requires full participation. Invoking item (b) confirms that some high-productivity firms may reject the free allocation, in which case the socially optimal emissions will not be achieved. Other allocation rules for which $\theta \neq -\frac{\tau^*}{\delta\omega}$ may induce full participation, but will lead to emissions such that $\frac{\partial \pi_i}{\partial e_{i0}} \neq \tau^*$. $\square$

Proposition 3 has important implications for the efficiency of an anticipated future market. Under traditional Grandfathering, all firms will choose to accept their free allocation of rights, and knowing this, they will adhere to the incentives engendered by anticipation. This implies that all firms will increase emissions relative to the completely unregulated case where no future market is anticipated, and paints a grim picture of the tragedy of the commons under the anticipation of traditional Grandfathering. But the story is somewhat different when using a Reverse-Grandfathering rule. In that case, some firms will accept the free allocation and, with sufficient heterogeneity, others may choose to reject it. Those that accept will reduce emissions ahead of time (to earn a larger free allocation, recalling that $\theta < 0$), and any firms that reject the allocation will stick to the unregulated emissions. Importantly, though, no firm will choose to increase emissions, as was the case with traditional Grandfathering.

Thus, in comparing an anticipated future market to no market at all, we can conclude the following. First, if traditional Grandfathering is anticipated, aggregate emissions will be larger with the market than without it. Second, if Reverse-Grandfathering is anticipated, aggregate emissions will be smaller with the market than without it. Finally, only in the special case where Reverse-Grandfathering is anticipated, with $\theta = -\frac{\tau^*}{\delta\omega}$, and with full participation, will the socially-optimal emissions be achieved in advance of the market.

What role does endogenous environmental quality, Q, play in these period-0 conclusions? Recall that equilibrium Q and e are determined by the crossing of $Q(e)$ (which is decreasing in e, is determined by nature, and is independent of incentives) and $e(Q)$ (which is increasing in Q and is determined by the incentives derived above). For any given Q, aggregate emissions are increasing in θ, implying that $e(Q|\theta_L) < e(Q|\theta_H)$ for $\theta_L < \theta_H$. Therefore, since $Q(e)$ is downward-sloping, this implies that higher θ gives rise to higher equilibrium emissions and lower environmental quality.

5.2 Entry

Anticipation of a free future allocation could induce period-0 entry relative to the case when no future market is anticipated. Since high-productivity firms will already be present, we are mainly concerned with entry by low-productivity firms, and to the extent that these entering firms emit positive emissions, both environmental quality and welfare may be affected. Here we ask: How does anticipation of a future market affect period-0 entry and subsequent environmental quality and welfare?

We assume here that a firm enters only if the profit it earns will exceed a threshold value $\bar{\pi}$.[22] Consider a particular allocation rule (F,θ) and denote by γ_L the lowest-productivity entrant, so firm L's present value period-0 profit is exactly equal to zero:

$$V_{L0} = \pi_L(\hat{e}_{L0}, Q_0) + \delta\omega(F + \theta\hat{e}_{L0}) - \bar{\pi} = 0,$$

where we have invoked Proposition 3a and 3b, which establish that all low-productivity firms participate in the free allocation. Now consider how an increase in θ affects firm L's profits. If L's profits increase (above zero), then increasing θ will lead to entry. If L's profits decrease, then increasing θ will lead to exit. Total differentiation

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[22] Including $\bar{\pi}$ in the model above does not change any of the conclusions stated thus far.

gives:

$$\begin{aligned}
\frac{dV_{L0}}{d\theta} &= \frac{\partial \pi_L}{\partial e_{L0}}\frac{\partial e_{L0}}{\partial \theta} + \frac{\partial \pi_L}{\partial Q_0}\frac{\partial Q_0}{\partial e}\frac{\partial e}{\partial \theta} + \delta\omega\left(e_{L0} + \theta\frac{\partial e_{L0}}{\partial \theta}\right) \\
&= \underbrace{\frac{\partial e_{L0}}{\partial \theta}\left(\frac{\partial \pi_L}{\partial e_{L0}} + \delta\omega\theta\right)}_{=0} + \frac{\partial \pi_L}{\partial Q_0}\frac{\partial Q_0}{\partial e}\frac{\partial e}{\partial \theta} + \delta\omega e_{L0} \\
&= \underbrace{\frac{\partial \pi_L}{\partial Q_0}\frac{\partial Q_0}{\partial e}\frac{\partial e}{\partial \theta}}_{<0} + \underbrace{\delta\omega e_{L0}}_{>0}
\end{aligned}$$

The second line is just a rearrangement of the first, and the underbraced term in the second line equals zero by the envelope theorem. The final line reveals two opposing effects as θ increases. The first term shows that as θ increases, it causes aggregate emissions to increase, which lowers environmental quality; this effect always reduces firm L's profit. But there is a direct effect that firm L receives a larger free allocation; this effect always increases firm L's profit. If environmental quality and firm profits are not too tightly linked, then the second term will always outweigh the first, and an increase in θ will attract entry by low-productivity firms. Finally, we note that an increase in F unambiguously increases V_{L0}, which induces entry by low-productivity firms. However, even if changes in θ or F induce entry by low-productivity firms, these entrants' emissions will be low (by the virtue of their low productivity), so they cause only small distortions. In the structural simulations that follow, we are careful to endogenize entry, but we find that its empirical effects are minor.

6 Structural Simulations: A Market for Fishing Rights on the High Seas

We have shown how anticipation of a future market affects behavior and welfare even in the absence of any regulation. We have used those insights to derive an allocation rule, Reverse-Grandfathering, that can help address the market failure long before any regulation is actually implemented. Here we apply our model and the insights derived above to a structural policy simulation of global significance: a market for high seas fishery harvest rights. We first demonstrate that the model used in the previous sections can be adapted to a renewable resource extraction setting.

Accounting for growth of the fish stock, we begin by identifying the steady state induced by anticipation before the market goes into place and the steady state that arises from market equilibrium behavior after the market goes into place. In that analysis, we do not concern ourselves with the transitions to steady state. In reality, especially for some renewable resource stocks, these transitions can take time and can give rise to their own dynamic incentives. We study that more involved setting in Section 7.

6.1 Parameterizing the model to high seas fisheries

Here we show how the model presented in Section 3 can be parameterized to represent high seas fisheries. In fisheries, the analog to "emissions" is the "extraction" (e_{it}) by firm i. Environmental quality is given by the stock of fish (Q_t), and social welfare consists of fishery profits,[23] which are single-peaked in extraction and strictly increasing in fish stock. We adopt the following expression for firm i's profit:

$$\pi_i(e_i) = pe_i - \frac{e_i^2}{\gamma_i Q} - \bar{\pi} \tag{16}$$

where p is output price per unit extraction (we assume p is constant[24]), γ_i is firm i's productivity, and $\bar{\pi}$ is reservation profit.[25] Q is the contemporaneous resource stock, which evolves according to

$$\dot{Q} = G(Q) - \sum_i e_i, \tag{17}$$

for a concave, single-peaked growth function $G(Q)$. One possibility is the familiar logistic form: $G(Q) = rQ(1-Q/K)$, where r is the intrinsic biological rate of growth of the population and K is the carrying capacity; we will adopt this simple model in what follows.

It is straightforward to confirm that this fishery model adheres to the assumptions about the shape of firm i's profit invoked in Section 3. First, profit is concave in extraction: $\pi_i''(e_i) = \frac{-2}{\gamma_i Q} < 0$. Second, profit depends positively on environmental quality (i.e. stock): $\frac{\partial \pi_i}{\partial Q} = \frac{e^2}{\gamma_i Q^2} > 0$. Third, steady state environmental quality depends negatively on aggregate extraction: from Equation 17, increasing e always causes the stock to shrink: $\frac{\partial \dot{Q}}{\partial e} = -1 < 0$. Fourth, a firm's profit depends positively on productivity: $\frac{\partial \pi_i}{\partial \gamma_i} = \frac{e^2}{\gamma_i^2 Q} > 0$. Finally, marginal profit depends positively on

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[23] We abstract away from other sources of welfare, such as consumer surplus, ecosystem services or existence value of environmental goods, though these could easily be included.

[24] Indeed, the entire catch of the high seas is only about 6% of global wild fish catch, so fluctuations in high seas catch have little effect on price.

[25] This could also be interpreted as a fixed cost of entry.

productivity: $\frac{\partial^2 \pi_i}{\partial e_i \partial \gamma_i} = \frac{2e_i}{\gamma_i^2 Q} > 0$.

6.2 Unregulated incentives

In the absence of regulation, and without anticipation of a future environmental market, firm i will extract at any instant to the point where profit is maximized, taking the resource stock Q as given, so the first order conditions imply

$$e_i = \frac{p\gamma_i Q}{2}, \qquad \text{so} \tag{18}$$

$$e = \frac{pQ\sum\gamma_i}{2}, \qquad \text{and} \tag{19}$$

$$\pi_i = \frac{p^2\gamma_i Q}{4} - \bar{\pi}. \tag{20}$$

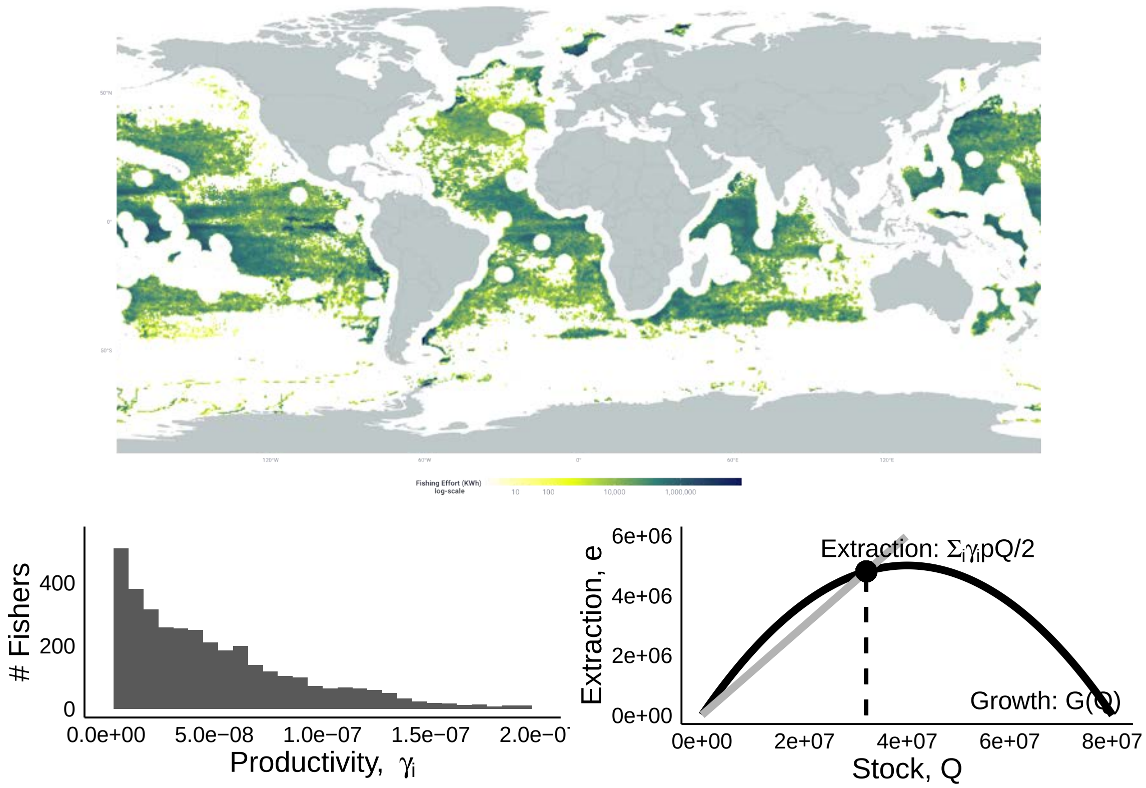
Thus, endogenizing entry, all firms with productivity greater than $\underline{\gamma} = \frac{4\bar{\pi}}{Qp^2}$ would enter and extract a positive amount.

This behavior delivers an aggregate extraction $\sum e_i$, which, when combined with Equation 17, determines whether the stock Q instantaneously grows (if $\dot{Q} > 0$) or shrinks (if $\dot{Q} < 0$). Eventually, a steady state extraction and resource stock is achieved. Assuming logistic growth, in the absence of any regulation, and without anticipation of a future market, the economy-environment equilibrium of this behavior turns out to be:

$$\bar{Q} = K\left(1 - \frac{p\sum\gamma_i}{2r}\right), \tag{21}$$

The associated steady state extraction is $\bar{e}_i = \frac{p\gamma_i}{2}\bar{Q}$; both are shown in the bottom right panel of Figure 1. The hump-shaped curve is steady state of the logistic biological growth equation ($e = rQ(1-Q/K)$), the upward-sloping line is the aggregate extraction as a function of the resource stock derived from the first order condition (Equation 19), and the solid point is the equilibrium extraction and stock that arises in equilibrium.

Figure 1: Simulation Data and Parameterization



Notes: The top panel shows pixel-level high seas fishing effort in 2018 from Global Fishing Watch. The bottom left shows the distribution of the productivity parameter derived for all participants in the high seas fishery. And the bottom right illustrates the biological steady state ($G(Q)$) with unregulated fishing incentives (from Equation 18).

It is straightforward to see from Equation 21 that the unregulated equilibrium resource stock is declining in the aggregate productivity and price and increasing in the biological growth rate and carrying capacity. But, owing to concave biological growth, it turns out that equilibrium *extraction* could be increasing, or decreasing in aggregate productivity, depending on whether $\bar{Q} \lesseqgtr K/2$. Holding the stock constant, and comparing a high productivity (high γ_i) vs. a low productivity (low γ_i) firm, the high productivity firm will always extract more than the low productivity one.

6.3 High Seas Data

The high seas is the oceanic area beyond any nation's jurisdiction (200 nm), covering an area of approximately 62% of the world's ocean. This massive expanse harbors many of the world's iconic species such as bluefin tuna, great white sharks, billfish, and whales. Despite the global importance of these (and other) species, little effective management is bestowed on the high seas because no country has jurisdiction, so any effective intervention requires an international agreement. While some such agreements exist, fishing on the high seas remains largely unchecked by regulation.

New estimates of the fishing activity and profits from fishing the high seas accord with this expectation. Sala et al. (2018) used data on fishing activity by all large fishing vessels on the high seas to estimate aggregate costs, and matched these costs with revenue data to estimate the profit from fishing. They found that, after accounting for subsidies provided by many high seas fishing nations (principally China, Taiwan, and Japan), high seas revenue (about \$7.7B/yr.) is approximately the same as estimated cost (\$6.2B-\$8.0B/yr.), suggesting that indeed they may be operating near unregulated equilibrium.[26]

However, at the individual firm (fishing vessel) level, inframarginal rents likely remain. These rents accrue to productivity in the manner described above. Our goal is to use vessel-level fishing data to parameterize our structural model. This will allow us to conduct policy simulations regarding different allocation approaches. To do so, we require empirical estimates of vessel-level productivity.

To derive fishing-vessel-level values of γ_i, we require individual, vessel-level data from the universe of fishers on the high seas. A decade ago, this would have been virtually impossible because almost nothing was known about who was catching what. Fortunately, a new satellite-based platform called Global Fishing Watch uses satellites to measure the real-time location and behavior of fishing vessels, and curates this information for research purposes.[27] From that dataset we extract Automatic Identification System-detected (AIS)-derived vessel-level fishing effort for the universe of detectable vessels in 2018. AIS is mandated for all vessels over 300 GT (and all passenger vessels), and it is estimated that at least 90% of fishing effort on the high seas is AIS-detectable. For the purposes of this illustration we assume that the Global Fishing Watch data are representative of the universe of high seas fishing. This allows us to individually track the fishing activity of 4,898 fishing vessels, including each vessel's estimated catch during 2018 (Figure 1). We use these data and our model to develop policy simulations to examine the consequences of a

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[26] In contrast, consider a coastal fishery with strong property rights such as the red snapper fishery in the Gulf of Mexico. In that fishery, the lease price for fishing rights was very high - about 70% of the output price - suggesting that revenue was significantly smaller than cost in that regulated setting Grainger and Costello (2015).

[27] See `www.globalfishingwatch.org`.

hypothetical, but plausible, market for fishing rights on the high seas.

6.4 Parameterization

While it is surely a stylization of a complex reality, we proceed under the assumption that 2018 high seas catch occurred in the absence of regulation or anticipation.[28] Under this assumption, we can adopt Equation 18 to infer what the productivity of every fisher must have been to rationalize her observed catch: Fisher i's productivity is given by $\gamma_i = \frac{2e_i}{pQ}$. We use a composite price estimate and stock size from government stock assessment reports and the Ram Legacy Stock Assessment Database (Ricard et al. 2012) for our estimates of $p =$ \$1,500/MT and $Q =$ 32MMT;[29] these imply an aggregate unregulated steady state catch on the high seas of 4.8MMT. Taken together, these imply productivity levels of the 4,898 fishers ranging from 1.2×10^{-13} to 2.7×10^{-6}, with a median of 2.3×10^{-8}. The full distribution of productivity levels is shown in the bottom left panel of Figure 1. We use $\bar{\pi}$ =\$10,000 as the reservation profit.

6.5 Anticipating a future allocation

Following the experience from real-world individual transferable quota markets in fisheries, we structure the hypothetical future high seas fishery market as follows. At some future date, fishers with a history of fishing on the high seas will receive an allocation of rights following the formula $A(e_{i0}) = F + \theta e_{i0}$, for some $F \geq 0$ and

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[28] Alternatively, it is straightforward to use this model to back out γ_i under *any* baseline anticipation incentives.

[29] MT is metric tons. MMT is million metric tons.

$\theta \lesseqgtr 0$. After these rights have been allocated (for example, ten years hence), the total allowable catch of fish will be determined and enforced in order to return the largest possible post-market welfare to fishers. While we ignore any other ecosystem services possibly provided by fish (for example, ecosystem services or other use or non-use values), those could easily be accommodated in this framework.

Accounting for both periods, fisher i's present value payoff in period-0 is:

$$\pi_i(e_{i0}, e_{i1}) = \underbrace{pe_{i0} - \frac{e_{i0}^2}{\gamma_i Q_0} - \bar{\pi}}_{\text{Pre-market payoff}} + \underbrace{\delta \left(F + \theta e_{i0} + pe_{i1} - \frac{e_{i1}^2}{\gamma_i Q_1} - \bar{\pi} - \tau^* e_{i1} \right)}_{\text{Present value of post-market payoff}} \tag{22}$$

The pre-market payoff is straightforward. In the post-market period, two new terms show up. The first is the free allocation, $F + \theta e_{i0}$, which depends only on i's extraction in the pre-market period, and $\tau^* e_{i1}$, which is the market-clearing trading price during period-1 (τ^*) multiplied by the period-1 extraction by firm i. Because all fishers are small relative to total extraction, we assume they are "stock-takers," i.e. that they ignore their own effect on the stock, and they take Q_t as given. The adding up condition requires that steady state stock levels Q_0 and Q_1 must satisfy: $\sum_i e_{it} = rQ_t(1 - Q_t/K)$, for $t = \{0, 1\}$. Here we invoke discount factor $\delta = .9$ and for simplicity assume the future market is anticipated with probability $\omega = 1$.

The aggregate allocation of rights in this institution is given by $\sum_i F + \theta e_{i0}$, and the market capitalization of all rights is $\sum_i \tau^* e_{i1}$. If the value of allocation of rights exceeds the market capitalization, then some rights will be bought back by the regulatory agency (so this will represent a net expenditure of public funds). If the value of allocation of rights is less than the market capitalization, then there will be net revenue generated (so this will represent a net increase in public funds). For most of this analysis, we will assume that the desired allocation is revenue neutral to the implementing body. This is consistent with the common practice of allocating the right to catch percentages of the total allowable catch, where the percentages add up to 100%. To analyze the incentives before the market goes into place, we must work backwards, starting with the post-market equilibrium.

6.6 Post-market behavior

We assume that the regulator's period-1 objective is to maximize aggregate profit in the fishery by setting a total allowable catch (call it e_1) and allowing frictionless trade among all firms. In this steady-state model, the regulator chooses e_1 to maximize steady state profit.[30] Because e_1 is chosen optimally, the market-clearing price is τ^*. Regardless of i's free allocation of rights, the opportunity cost of each ton of fish catch is τ^*.

Once the market materializes, fisher i takes the market clearing price as given and decides how much to extract, so she solves:

$$\max_{e_{i1}} pe_{i1} - \frac{e_{i1}^2}{\gamma_i Q_1} - \tau^* e_{i1} - \bar{\pi}. \tag{23}$$

Taking the first order condition and rearranging implies that in the post-market

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[30] We later account for transition dynamics by solving a more complicated dynamic optimization problem once the market goes into effect; that approach leads to a sequence of harvests over time, rather than a single optimized value in steady state.

period, fisher i extracts

$$e_{i1} = \frac{(p - \tau^*)\gamma_i Q_1}{2}. \tag{24}$$

In the post-market setting, the regulator seeks to solve:

$$\max_{\tau^*} \sum_{i=1}^{4{,}898} \left(pe_{i1} - \frac{(e_{i1})^2}{\gamma_i Q_1} - \bar{\pi} \right). \tag{25}$$

Now extraction by each firm i = 1,2,... is given by the incentives in Equation 24, and the entire system must be in equilibrium, so Q_1 is endogenous to τ^*. To ensure that the system is in equilibrium: $\sum_i e_{i1} = rQ_1(1 - Q_1/K)$. With our data, these conditions imply an optimal market clearing price of τ^* =\$594/MT (i.e. harvest rights' market value is about 40% of the sales price of fish), which gives rise to an aggregate catch of e_1 = 4.6 MMT, a resource stock of Q_1 = 51MMT, and an aggregate permit value of \$2.7B per year. Since the allocation rule has no impact on post-market incentives, all of these results are independent of the allocation formula.

If we wish to maintain revenue neutrality for the implementing agency, the permit value must equal the monetary value of all rights. Since the permit value is \$2.7B, this implies that the aggregate free allocation must also be valued at \$2.7B. While we generally consider allocation rules that meet this criterion, for completeness we also examine allocation rules that over- or under-allocate the extraction rights.

6.7 Allocation rules and pre-market incentives

Stepping back to the pre-market period (period 0), we now ask how anticipation of a future allocation affects pre-market extraction incentives. In period-0, a participating fisher i solves

$$\max_{e_{i0}} = pe_{i0} - \frac{e_{i0}^2}{\gamma_i Q_0} - \bar{\pi} + \delta(F + \theta e_{i0}), \tag{26}$$

which has first order condition

$$e_{i0} = \frac{\gamma_i Q_0 (p + \delta\theta)}{2}. \tag{27}$$

Thus, for any given period-0 resource stock (Q_0), participating fisher i will extract the amount shown in Equation 27. This has the expected properties that i's pre-market extraction is increasing in productivity, resource stock, price, and θ. Thus, the larger is the free grandfathering subsidy, the larger is i's pre-market extraction, for *any* extant resource stock. Note also that i's extraction is increasing in δ when $\theta > 0$ and decreasing in δ when $\theta < 0$. This result arises because when $\theta > 0$, higher pre-market catch is rewarded when the market is implemented. A higher δ implies more patience, so that incentive is amplified and higher extraction ensues. But when $\theta < 0$, higher pre-market catch is actually penalized on the margin. Thus when δ is larger this effect is amplified, which leads to lower period-0 extraction.

6.7.1 Optimal Reverse-Grandfathering (Ignoring Participation)

Ignoring endogenous participation for the moment, Equation 27 can be used to solve for the equilibrium stock, extraction, and payoffs to all 4,898 fishers under any allocation rule. In this case it is straightforward to see that the regulator would like to set a *penalty* for excessive harvest in period-0 rather than a *reward.* In other words, it is intuitive that the socially-optimal value of θ would be negative. One way to see that is to inspect the post-market optimization problem presented in Section 6.6. In that problem it was optimal to set a *tax* of \$594/MT. Since the payoffs are identical between the two periods, this must also be optimal in period 0. But because there is no regulation in period 0, the regulator can cleverly manipulate incentives by causing fishers to *anticipate* a future value of θ that gives rise to the same incentives. Doing so requires accounting for the discount factor, so the "auction-equivalent" value of θ is $\theta = -\tau^*/\delta$. If the regulator commits to a future allocation rule with $\theta = -\tau^*/\delta$ (in this example, with $\delta = .9$, θ =-\$660), then this perfectly induces market-like incentives in the unregulated setting. The value of F is somewhat immaterial here, although only a single value of $F > 0$ will be revenue-neutral.

6.7.2 Optimal Allocation Considering Participation

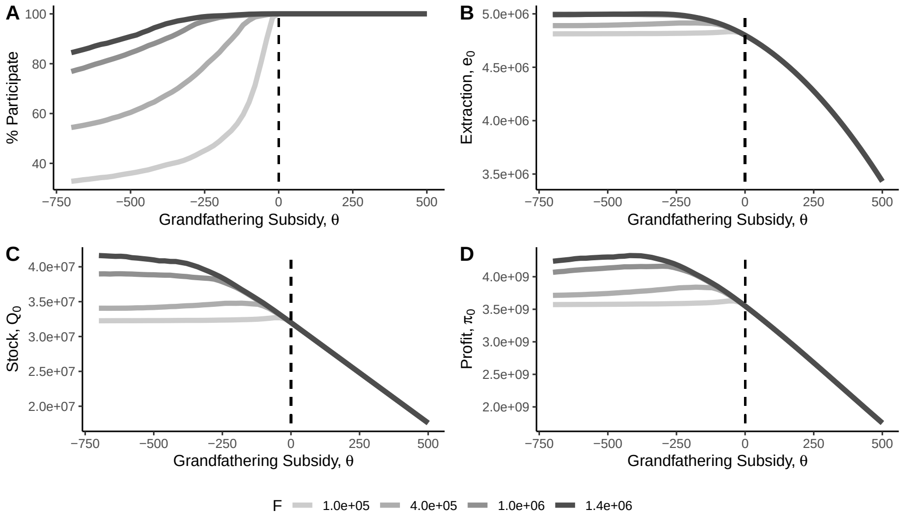
The problem with setting $\theta = -\tau^*/\delta$ is that it ignores the participation constraint. Recall that by "participation" we are referring to the incentives for i to accept or reject the free allocation of rights once the market goes into place: fisher i will accept the free allocation if, for any given stock Q_0, accepting the free allocation yields higher profit than rejecting it. If i accepts the free allocation, then she will abide by the incentives given by Equation 27. If i rejects the free allocation, then she will abide by the incentives given by Equation 18. Participation becomes pivotal with Reverse-Grandfathering because the high-productivity fishers (those who wish to extract the most in period-0), are those who obtain the lowest allocation; this concern does not arise under traditional Grandfathering. In the extreme, when θ is large and negative, a high-productivity fisher could actually face a negative allocation (and will thus rationally reject the free allocation). And since i's extraction depends on whether she will accept or reject the free allocation, the entire enterprise becomes endogenous.

Intuitively, then, the problem with trying to replicate the first-best auction price with an anticipated Reverse-Grandfathering rule (that is, the problem with setting $\theta = -\tau^*/\delta$) is that the high-productivity fishers will not participate and will thus overextract in period 0. Any fisher that defects from the allocation will extract more than she would have extracted under participation, and thus, the efficiency of the market cannot be replicated in the pre-market anticipatory setting. This induces a second-best setting and presents the market designer with a tradeoff between efficiency and participation.

Any allocation rule can be completely characterized by its (F, θ) pair. For any such allocation rule, we can determine which fishers will participate and enter, each fishers' extraction, and the resulting period-0 resource stock and profit. Figure 2 displays the period-0 fraction of participating fishers (panel A), equilibrium extraction (panel B), equilibrium fish stock size (panel C), and equilibrium profit (panel D) under anticipation of a hypothetical future market for fishing rights on the high seas. The horizontal axis is the grandfathering subsidy θ (where values of $\theta > 0$ indicate traditional Grandfathering and values $\theta < 0$ indicate Reverse-Grandfathering; $\theta = 0$ is indicated with a dashed vertical line). We plot these values for different levels of the fixed subsidy, F.

It is instructive to examine a few special cases. First, consider the case where there is no marginal subsidy, so $\theta = 0$. This would be the case if market rights

Figure 2: Equilibrium Outcomes with Endogenous Participation



Notes: Each figure shows an outcome plotted against the grandfathering tax/subsidy (θ) for different values of the lump-sum payment, F, accounting for endogenous entry and participation. Panel A plots the percentage of firms participating in the allocation rule; B shows aggregate period-0 extraction; C shows period-0 stock; and D shows period-0 profit.

were allocated equally among all participants. In that setting, all firms participate (panel A) and the resource stock equilibrates at an intermediate level. Note also that when $F = 0$, these results are identical to the results assuming no regulation and no anticipation (Section 6.4) because this no-allocation case engenders incentives identical to the case when no market is ever anticipated. Second, consider the case of traditional grandfathering ($\theta > 0$). Anticipation of this grandfathered allocation drives over-extraction in period-0. For example, if $\theta = 500$, the resource stock is depleted to $Q_0 = 17.6$MMT and steady state extraction declines to $e_0 = 3.4$MMT. These special cases of $\theta \geq 0$ illustrate the possible empirical magnitude of deleterious effects of anticipating grandfathering on pre-market incentives.

To counteract these incentives, consider Reverse-Grandfathering. When $\theta < 0$, the incentives work in the opposite direction, so prudence in period-0 is eventually rewarded at the beginning of period-1, though we need to carefully consider participation. For example, consider the naive allocation rule that attempts to reproduce the incentives of the market by setting $\theta = -\tau^*/\delta = -594/.9$ =-\$660/MT and $F = 0$. In theory, if participation were ensured, this allocation rule would precisely reproduce the welfare-maximizing extraction by all fishers. The problem with this allocation rule is that the participation constraint fails for all 4,898 fishers. In other words, when $\theta < 0$ and $F = 0$ each and every fisher earns higher profit by failing to participate (that is, by foregoing the free allocation and adhering to unregulated incentives in period-0) than by participating. The result gives rise to an equilibrium that is exactly the same as in the unregulated setting without anticipation (resource stock of $Q_0 = 32$MMT). Holding θ =-\$660/MT and increasing F (moving vertically in Figure 2A), it is clear that participation can be incentivized (with higher F). For example, if F =\$450,000, then participation jumps to about 60%. Those who participate extract less, and the end result is an equilibrium stock of $Q_0 = 35$MMT.

While every allocation policy (F, θ) gives rise to different ecological and welfare consequences, each also implies an outlay of public funds. The larger are F and/or θ, the larger is the outlay of funds, recognizing that the exact amount depends on e_{i0} and Q_0, and is therefore endogenous.[31] While this analysis can handle positive, negative, or neutral outlays of public funds, we focus attention on the set of possible allocations (F, θ) that are revenue neutral, after accounting for endogenous entry and participation. For entry, we focus on the set of 4,898 fishers in our dataset and for any allocation rule and auction price, determine which fishers will enter. For participation, we apply the participation constraint to determine who participates in the free allocation of rights, and how that decision affects period-0 extraction by each firm.

We can use this set of revenue neutral allocation rules to identify the *socially optimal* second-best allocation rule. In principle, we would like to find the revenue-neutral allocation that maximizes period-0 social welfare, endogenously accounting for entry and participation. Figure 3 shows welfare for every possible θ, holding F fixed at the level that achieves revenue neutrality for that particular value of θ (F is indicated by point size), after endogenously accounting for entry and participation. As we proved theoretically, due to the participation problem, $\theta^* \neq -\tau^*/\delta$. Taking all of this into account, the welfare-maximizing Reverse-Grandfathering rule is: $\theta^* =$

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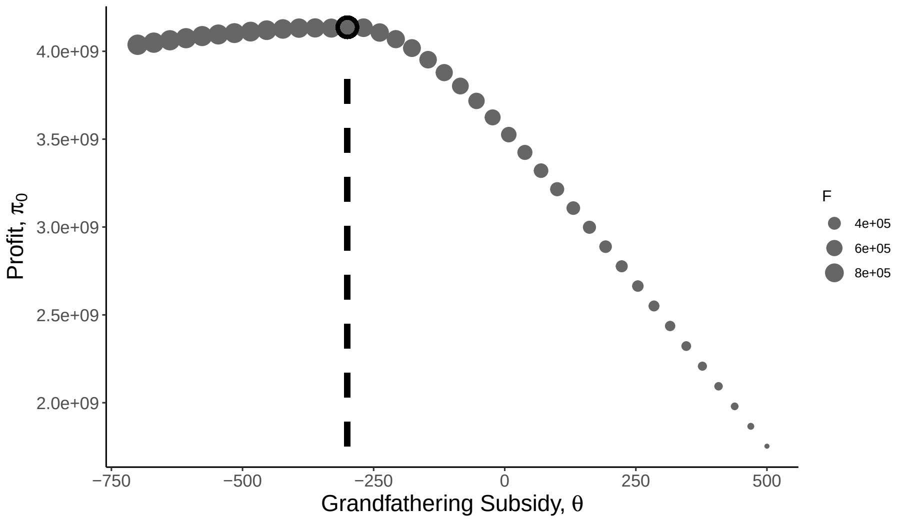
[31] We emphasize here that all results and figures account for these endogenous dynamics.

$-\$300/MT$ and associated revenue-neutral lump sum transfer of $F=$\$809,000. More negative values of θ can deliver revenue neutrality, but the participation constraint drives away too many high-productivity fishers, and this compromises welfare. Less negative values of θ are also viable for a revenue-neutral market design, but these weaken the marginal incentives for period-0 extraction, so also compromise welfare. Overall, these results support the adoption of a Reverse-Grandfathering rule for high seas fisheries, and soundly reject traditional Grandfathering on both ecological and welfare grounds.

Figure 3: Aggregate Pre-Market Profits for Different Revenue-Neutral Allocations



Notes: The figure plots period-0 profits against grandfathering subsidy/tax levels (θ). The lump-sum payment, F, is illustrated by the size of each dot. The welfare-maximizing allocation pair for θ and F is illustrated with the dashed line.

6.8 Political Economy

The analysis above endogenizes both entry and participation, and derives an optimal second-best allocation rule. If that allocation rule were followed, it would engender certain incentives for all 4,898 high seas fishers—some would participate, and others would not. This behavior by each fisher gives rise to equilibrium outcomes in each period. Here we pose an explicit political economy question: Does fisher i prefer this market setting (unregulated in period-0 with anticipation of a Reverse-Grandfathering allocation in period-1, and subsequent welfare-maximizing market exchange in period-1) or a completely unregulated setting in which no market is ever implemented? The structural nature of our simulations, along with our measure of heterogeneous productivity, allows us to examine this question for each fishing firm. In thinking through the incentives some intuitive conclusions can be drawn.

First, consider a relatively low-productivity firm. In the absence of a market, this firm would catch relatively few fish and would earn very low profit. Instead, under optimized Reverse-Grandfathering, this firm would enjoy a higher stock in period-0 (this raises period-0 profit) and would enjoy a higher stock and a large free allocation in period-1. For such a fisher, both effects tip the scales toward the market setting.

Now consider a very high-productivity firm. We showed in Proposition 3 that sufficiently high-productivity firms will fail the participation constraint and will therefore be governed by the unregulated incentives in period-0. But such a defecting firm will still enjoy a higher stock in period-0 (because lower-productivity firms do participate). Thus, high-productivity firms benefit from others' anticipation of a market with Reverse-Grandfathering. However, once the market arrives, these very high productivity firms will have to buy all fishing rights at the price τ^*. Despite the fact that the market gives rise to a higher period-1 stock, this cost is likely to lead high-productivity firms to prefer the completely unregulated setting to the Reverse-Grandfathering market.

Using the parameterization derived above, we find that 81% of fishers prefer the Reverse-Grandfathering Market over the alternative of no regulation. However, consistent with the intuition provided above, we find that it is the high productivity firms that comprise the 19% of disadvantaged fishers. If political power is correlated with profits (and therefore productivity, in this model), then it is quite possible that the 19% of disadvantaged fishers could sway the politics toward the unregulated setting, despite the aggregate welfare and environmental gains that arise under optimized Reverse-Grandfathering.

6.9 Comparing Results Across Market Scenarios

The example so far illustrates the main finding of this paper: anticipating a future environmental market affects efficiency and environmental quality. But how large are the differences across market scenarios? Here we compare period-0 results across four alternative market scenarios: (1) no regulation (and no anticipation of a future market), (2) anticipation of traditional Grandfathering, (3) anticipation of welfare-maximizing Reverse-Grandfathering, and (4) immediate implementation of a market (we regard this as impractical, but provide it as a benchmark). Results are displayed in three ways. Figure 4 panels A-C produce bar graphs of the results, all scaled relative to the no regulation benchmark. Figure 4D shows how biology of high seas fisheries interacts with these economic incentives to give rise to the results. Finally, Table 2 provides the quantitative results across market scenarios.

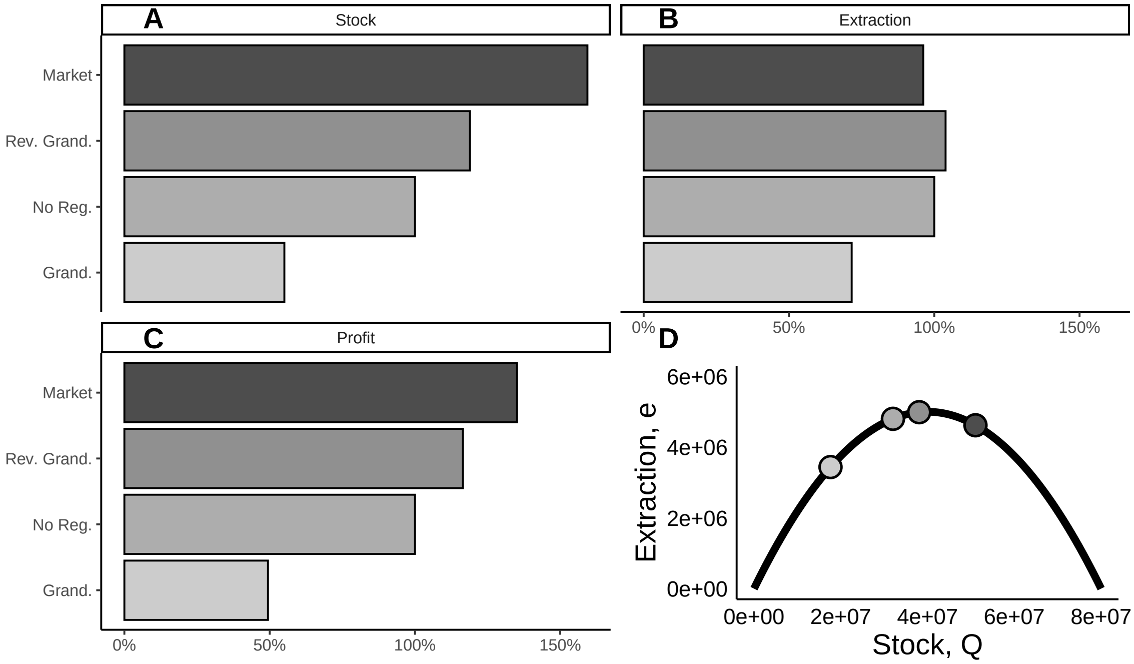
Traditional Grandfathering gives rise to the worst possible outcome among the market scenarios considered here. Equilibrium welfare, fish catch, and fish abundance are all substantially lower under Grandfathering than they would have been under no regulation at all (by -50%, -28%, and -45%, respectively). Reverse-Grandfathering goes a long way toward correcting these inefficiencies. Compared to no regulation, Reverse-Grandfathering actually improves all three measures (by +16%, +4%, and +19%, respectively), not only neutralizing the effects of Grandfathering, but reversing them. However, consistent with the theory developed above, endogenous participation prevents Reverse-Grandfathering from completely replicating the full-market outcome; it falls short on welfare (by -14%) and resource stock (by -25%) but due to the hump-shaped biological growth, actually delivers higher fish catch (by +8%) than the market scenario.

Table 2: Simulation Results for Alternative Market Scenarios

Market Scenario	Stock (Q_0)	Welfare (π_0)	Extraction (e_0)
No Regulation	3.2E+07	3.6E+09	4.8E+06
Reverse-Grandfathering	3.8E+07	4.1E+09	5.0E+06
Immediate Market	5.1E+07	4.8E+09	4.6E+06
Traditional Grandfathering	1.8E+07	1.8E+09	3.4E+06

Notes: Period-0 steady state results for each market scenario.

Figure 4: Equilibrium Stock, Extraction, Profit and Biological Steady State



Notes: Panels A-C illustrate outcomes in period-0, relative to what is obtained under no regulation (panels A-C). Panel A shows the stock level that would occur in a market-based equilibrium as the first-best baseline. Stock levels under Reverse-Grandfathering, No Regulation, and Traditional Grandfathering are then shown. Panels B and C show analogous plots for Extraction and Profits, respectively. Panel D illustrates the biological model and the resulting steady state under each allocation rule.

7 Transition Dynamics

Thus far we have assumed that they system is in steady state in each of the two periods, and have ignored transition dynamics. In real world settings, transition dynamics may prove important if environmental quality (or resource stocks, in the fisheries example) significantly affects decisions and has innate dynamic characteristics. Thus, when the resource stock plays only a negligible role, as with many pollution settings, the two-period model presented above is reasonable. But when the resource stock plays a vital role in firm decisions, dynamics can become more important. The purpose of this section is to illustrate those transition dynamics for the high seas fishery case studied above.

The main insight from this paper is that anticipation of a traditional Grandfathering rule affects emissions or extraction incentives before a market goes into place. In the fishery case, anticipating a Grandfathering rule leads to increased extraction, which drives down the resource stock. This process continues during the entire period of anticipation, and our simulations suggest that this results in a substantially lower stock under traditional Grandfathering than under Reverse-Grandfathering. Once a market is implemented, the regulator is assumed to maximize the net present value of the resource in perpetuity. The regulator does so by deriving an infinite horizon extraction policy function that is the result of a dynamic optimization, taking entry into account. She will, loosely speaking, have a bigger hole to dig out of if the market starts with a low stock (as it would under anticipation of a traditional Grandfathering rule) than if the market starts with a high stock (as it would under anticipation of Reverse-Grandfathering).

Thus, when fully considering the dynamic incentives engendered by anticipation of a market, we can consider the following three phases:

- **Pre-Anticipation Phase (lasting T_0 years)**: In this phase, extraction occurs as-if no market would ever be implemented. This is the canonical "unregulated" setting, and would be expected to deplete the stock to a relatively low level (though typically not zero). Entry is endogenous each period, and only fishermen who can earn positive contemporaneous profit (after accounting for opportunity cost, $\bar{\pi}$) will enter. For fisherman i who enters, it is straightforward to see that period-t extraction during this phase is given by:

$$e_{it} = \frac{p\gamma_i Q_t}{2} \tag{28}$$

- **Anticipation Phase (lasting T_1 years)**: At the beginning of this phase, fishermen anticipate a future market and allocation rule. In this dynamic setting, we generalize the allocation formula as follows: If fisherman i participates, then her free allocation is $\sum_{t=1}^{T_1} F + \theta e_{it}$, which is given at the date the market begins. With these incentives in mind, each fisherman must decide whether to enter and whether to participate. The entry decision occurs each year and occurs if positive profit can be made that year. The participation decision is made once and for all; that is, each fishermen either participates or she does not participate.[32] If she decides to participate, then she knows she will receive a free allocation of rights once the market goes into place, and over the entire anticipation phase, will respond to the incentives that arise from the future allocation. Under this model of dynamic allocation, participation gives rise to extraction:

  $$e_{it} = \frac{\left(p + \theta\beta^{T_1 - t}\right)\gamma_i Q_t}{2}$$

  where β is the annual discount factor (notably $\beta \neq \delta$) and the parenthetical term emphasizes that the future allocation parameter θ enters in a discounted

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[32] We implicitly assume rational expectations on the part of fishers.

manner; the closer time gets to the market date, the larger is the influence of θ on extraction. Instead, if she decides not to participate, then her incentives during this phase are as if no market will ever go into effect, so her extraction follows Equation 28. Calculating which fishers participate and which fishers defect requires numerically solving a dynamic equilibrium where we find the marginal fisherman who earns the same profit from participating or not, taking endogenous resource stock into account.

- **Market Phase (lasting T_2 years)**: At the beginning of this phase, the market goes into effect and the free allocations are made, according to the rule that was anticipated previously by fishermen. Each year, a quota is set and rights are traded, resulting in a quota trading price τ_t in year t, noting that both the quota and the price will be different each year as a consequence of the dynamic optimization. That is, the quota in any given year (and the quota trading price each year) is the result of a dynamic optimization problem solved by the regulator. The regulator's problem during this phase is to maximize the net present value of extraction profits over an infinite time horizon, which we implement by numerically solving this dynamic programming equation:

$$V(Q_t) = \max_{\tau_t} \left[\sum_i \max\left(0, pe^*_{it} - \frac{e^{*2}_{it}}{\gamma_i Q_t} - \bar{\pi}\right)\right] + \beta V(Q_{t+1}) \tag{29}$$

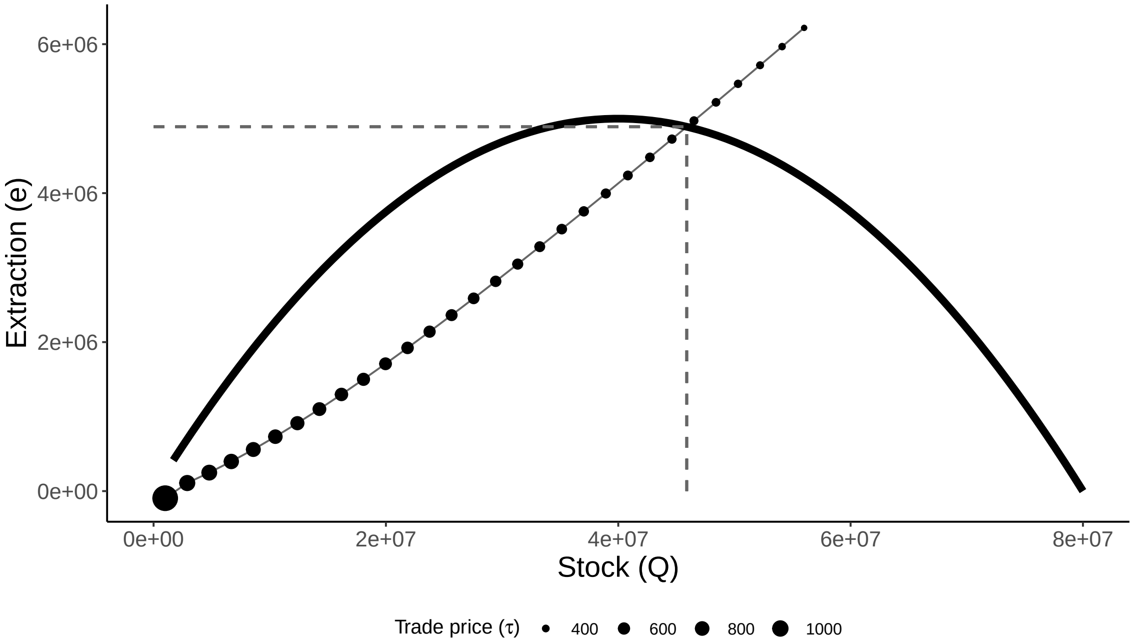
where the term in square brackets is the current period payoff, from the perspective of the regulator and fisherman i's extraction choice is given

$$e_{it}^{*} = \frac{\gamma_i Q_t (p - \tau_t)}{2} \tag{30}$$

The zero in Equation 29 reflects optimal entry - no fisherman would enter in period t unless she can earn positive profit. State transitions are given by: $Q_{t+1} = Q_t + rQ_t\left(1 - \frac{Q_t}{K}\right)$. We solve this dynamic program numerically with value function iteration. This gives rise to an optimal infinite horizon policy function, $\tau^{*}(Q_t)$ (or equivalently an optimal extraction cap $e^{*}(Q_t)$). The numerically derived optimal infinite horizon policy function is shown in Figure 5 as points. The vertical height of each point shows the optimal extraction cap associated with that level of resource stock. The size of each point shows the corresponding trading price that would arise in the market under that optimal extraction cap. The present value of the fishery is maximized by following this policy function every year during the Market phase, and it holds for any stock that is inherited at the beginning of this phase.

We implemented the procedure outlined above for a simulation where the Pre-Anticipation phase lasts $T_0 = 30$ years (and begins with a stock of 50 Million tons, about 63% of carrying capacity). The simulation over that period allows the stock to settle to near steady state of about 33 Million tons. The Anticipation phase in this simulation lasts $T_1 = 20$ years, and we examine the same four scenarios as in the main text (immediately implementing a market, Reverse-Grandfathering, Grandfathering, and no anticipation). Each of these scenarios engenders different incentives, and

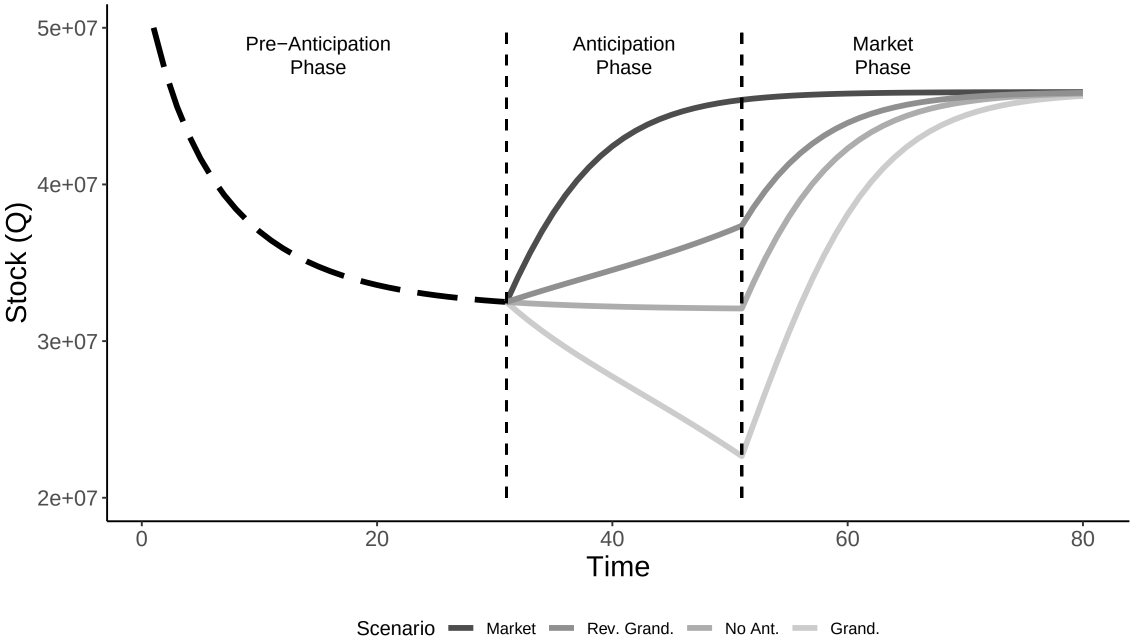
Figure 5: Optimal infinite-horizon policy function (points) and biology (solid) during the Market phase. Point size shows the trading price (τ) that results from each possible extraction cap. Dashed lines show the steady state of stock (Q) and extraction (e) under the optimal policy function.



leaves a different level of resource stock at the beginning of the market phase. Finally, we simulate a market phase of $T_3 = 30$ years, which is enough time for the optimal infinite horizon policy function to give rise to a steady state stock of about 46 Million tons. This is associated with an optimal steady state extraction quota of 4.9 Million tons, with a predicted trading price of \$430/MT. These results are shown in Figure 6. The figure aptly captures the key intuition of this paper. In the absence of any anticipation, the tragedy of the commons prevails and environmental quality will deteriorate for reasons that are familiar to economists. This is shown in the Pre-Anticipation Phase of Figure 6. In the Anticipation Phase of Figure 6, the fate of the environment hinges critically on what allocation rule is anticipated. If a traditional Grandfathering rule is anticipated, environmental quality deteriorates rapidly to a level substantially lower than was achieved under the tragedy of the commons alone. But under other approaches to allocation, such as Reverse-Grandfathering derived here, these incentives flip and environmental quality can recover substantially, even in the absence of any regulation. Finally, in the Market Phase, an optimal policy is pursued, which eventually leads to environmental quality recovery. This takes substantially longer, translating into larger welfare losses, if Grandfathering was anticipated. This occurs because of the stock nature of this problem.

This dynamic analysis emphasizes that when developing a market for a resource stock, such as fisheries, water, or carbon, there are two kinds of welfare losses that can arise from anticipation of a Grandfathering rule. The first welfare loss occurs in the Anticipation Phase when incumbents race to acquire larger free allocations. This loss was emphasized in the theory section of the paper. The second welfare loss occurs in the Market Phase itself. Because this phase begins with an inefficiently low resource stock, and value functions are increasing in the stock, there is a welfare deficit arising from inefficient historical behavior. This second effect reinforces the first effect, suggesting that stock problems may suffer more from Grandfathering than flow problems.

Figure 6: Dynamics during each of three phases, under alternative allocation rules.



8 Conclusion

Thanks largely to the contribution of economists over the past half-century, markets are increasingly the policy instrument of choice for environmental management. Successful markets have been implemented for carbon, air pollution, water, fish extraction, biodiversity, and many other resources. Indeed, we agree with the thousands of contributions that herald the efficiency gains *after* these markets are implemented.

Instead, this paper focuses on what happens in anticipation of a future market. In this phase, firms have strong incentives to change their behavior to secure a greater free allocation of rights when the market eventually arises. Thus, the anticipated allocation of rights in a market can have first-order welfare implications, even in the complete absence of regulation. This suggests a need to re-think Coase's Independence Axiom with a broader interpretation of intertemporal welfare that includes pre-market outcomes. Indeed, for problems with a resource stock, such as fisheries and water, even post-market welfare can be affected by anticipation, as was shown in Section 7.

In practice, environmental markets tend to use a grandfathering approach for the initial allocation of rights. While attractive for some practical reasons, grandfathering rewards excessive historical use, so the incentives work counter to economic efficiency. Arguably, the whole purpose of the market is to correct the externality of excessive emissions, so it seems counterproductive to commit to an allocation rule that incentivizes firms to emit even more than the no-regulation profit maximizing level. With these incentives in mind, we derive an alternative allocation rule that we call "Reverse-Grandfathering" in order to reward prudence prior to the market's introduction. We demonstrate that this allocation rule can reverse the perverse incentives from Grandfathering and that it can even induce behavior in the unregulated setting that replicates what would have been first-best. Importantly, firms are more likely to support Reverse-Grandfathering than auctioning the new rights, as firms still receive a free lump-sum allocation; it only changes the marginal incentive prior to the market's implementation. Rather than incentivizing a costly race for allocation, Reverse Grandfathering creates an incentive to reduce the externality-generating activity prior to the establishment of the market.

Rights may be granted based on historical use for both political and practical reasons. For example, if the initial allocation is given to firms based on historical activities, there are likely to be fewer frictions and lower transaction costs when a market is implemented, as the initial allocation may be closer to the market equilibrium than would be the case under Reverse-Grandfathering. However, neither political considerations nor transaction costs alone necessarily justify the practice of Grandfathering on distributional or efficiency grounds. Our model is meant to highlight an incentive problem and an alternative allocation method that can reverse the deleterious effects of Grandfathering when the rights in question involve an externality.

We develop a simple model that applies to externality settings, such as emissions from firms, and to natural resource settings, where a firm's extraction choice affects other firms' profits through the resource stock. We illustrate the model with two periods, a pre-market phase and a market phase, which allows us to examine the implications of anticipation on pre-market incentives. There are interesting potential problems that arise when the allocation rule is anticipated by firms. First, incumbents need to be compensated enough so that they "participate" in the allocation mechanism—this hinges on the high-productivity firms. Second, the distribution of productivity (or costs) and reservation profits must be such that there is not excessive entry due to the Reverse-Grandfathering allocation in the market period—this hinges on the low-productivity firms. But because low-productivity firms also emit low levels of pollution, we find that this latter distortion is less practically relevant for welfare.

When considering potential allocations, our model highlights an interesting tension between inducing entry by low-productivity firms and ensuring participation by high-productivity firms. This tension is amplified when there is more heterogeneity in the distribution of firm productivity. Interestingly the efficiency gains from trade are greatest with high heterogeneity, but at the same time heterogeneity makes solving the anticipation problem more difficult.

It is also important to consider political economy when designing the allocation rule. This could be as simple as considering what fraction of firms would be better off under the proposed allocation rule than under the unregulated equilibrium (in our example, 81%). One could also imagine weighting this calculation by a firm's relative size. Finally, one could also consider extensions to our model, where the probability that a firm places on any given allocation rule is a function of the distribution of income under that allocation rule.

We also note that while we have focused on linear allocation rules, introducing nonlinearities into the formula could potentially increase efficiency. For example, a piecewise linear allocation rule could be designed to minimize the number of new entrants the allocation would induce and also ensure participation by the high-productivity firms while still remaining budget neutral. We also note that our results rely only on the *perception* of a credible allocation mechanism by current resource users; this could be signaled in a number of different ways.

Our empirical example is based on fishing rights on the high seas, which historically has been unregulated, but, with international agreements and the use of new monitoring technologies, could conceivably transition to a market. This example highlights the importance of anticipation effects when the environmental problem has a stock element, as anticipation of a future allocation rule impacts the stock's dynamics. In this example, anticipation of a (traditional) Grandfathering rule depletes both welfare and extant fish stocks to dramatically low-levels (about half of what would have occurred without regulation or anticipation). But when Reverse-Grandfathering is used, both welfare and fish stocks increase substantially relative to the unregulated baseline, even after accounting for endogenous participation and entry.

We end with a note of humility. Economists deserve a great deal of credit for the rapid expansion of environmental markets to solve a wide array of environmental and resource problems. However, as markets proliferate, it is reasonable to expect that currently-unregulated firms and individuals will increasingly anticipate future markets, and adjust unregulated behavior accordingly. To the extent that traditional Grandfathering is anticipated, unregulated resource use around the world may, even today, be substantially worse than the pure no-regulation model would predict. Estimating the magnitude of anticipatory behavior, its welfare implications, and how it depends on expectations, are interesting empirical questions for future work to consider. We hope that future work also considers alternative allocation mechanisms that can enhance the efficiency of environmental policies while maintaining political tractability.

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