Policy Change Anticipation in the Buyback Context

Author 1 · Author 2 · Author 3

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Abstract To what degree might an anticipated policy change delay the fleet restructuring process initiated by a vessel buyback? This paper addresses the issue by estimating a restricted profit function to analyze an overcapitalized fishing fleet subject to restrictive regulation on the harvest of its primary target species. Fishermen’s expectations and likely responses to the future regulations regarding individual quotas are modeled in the context of a time-limited buyback program. The Polish trawler fleet targeting primarily cod provides an application. Analyzing potential individual quota tradability, we find that considerable shifts in disinvestment are to be found due to anticipated policy change. The mechanisms driving discrepancies include capitalized value of quota, as well as the tradability option capitalized into other inputs with inelastic supply.

Keywords overcapacity · policy anticipation · vessel buyback · Polish trawl fishery

1 Introduction

Excess capacity in fishing fleets remains one of the most pressing issues for the conservation and management of fishing industries. Two major approaches dominate the potential interventions to target fleet excess capacity. The first approach, by offering payments to remove capacity, directly purchases vessels...
to remove them from the fleet, i.e. a fleet decommissioning or buyback program. The second approach, by introducing rights-based management, creates economic incentives for the industry itself to remove redundant capacity. Buyback programs, despite often proving costly and ineffective in the long term (Clark et al 2005; Lindebo 2005; Curtis and Squires 2007), continue to receive widespread applications (Holland et al 2017), often to facilitate a transition to a stronger management system (Curtis and Squires 2007). However, the presumption that buybacks can be analyzed solely in terms of offered payments is inappropriate as expectations regarding future management play a great role in decision-making of vessel owners.

The topic of policy change anticipation is common in financial economics when the expectations influence inflation or interest rates (e.g. Drazen and Helpman 1988 or Burger 2004). Agricultural economics has also long evaluated how farmer adjustment to expected policy changes (Lagerkvist 2005). But strategic behavior in response to anticipated regulatory change is also observed in fisheries (Salas and Gaertner 2004). Berck and Perloff (1984) introduced rational expectations in fisheries by contrasting fishermen’s behavior based on myopic expectations with perfect foresight. The fisheries literature also provides empirical evidence. Jorgensen and Jensen (1999) concluded that anticipated future subsidies in EU fisheries stimulated investments in fleet capacity. Brandt (2003), analyzing differences in efficiency between two similar fisheries with different policy change expectations, found depressed productivity in the fishery that expects individual transferable quotas (ITQ) based on historical catch due to the increased opportunity cost of keeping vessels inactive during the transition period.

This paper addresses these issues of fleet excess capacity, buybacks, and policy change anticipation. The paper analyzes the rational fishing vessel owner’s decision-making and incentives for industry exit and individual quota adjustment created by a vessel buyback scheme under different expectations regarding future quota management under the two of options, non-transferability and transferability. It also analyzes how anticipating a transition to ITQs shifts disinvestment incentives (Abel et al 1996). This paper contrasts myopic and rational expectations within a behavioral model of fishing firms, and demonstrates that expectations regarding the future management system play a key role in the decision to exit the fleet (Wilen et al 2001). This paper thus builds upon the wide literature on exit incentives in fisheries (e.g. the review in Branch et al 2006), but extends the topic to investigate whether similar strategic behavior can be observed for utilization of vessel buyback programs.

Using a definition of the value of the firm similar to Vestergaard et al (2005), we model incentives to disinvest, and compare optimal fleet structure

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1 Abel et al (1996) state that "opportunities for future expansion or contraction [of capital] can be valued as options."
development between scenarios that vary by the expectation for introducing quota tradability. This approach distinguishes our paper from the standard literature on capacity utilization that considers marginal capital adjustments in the long run (Morrison 1985; Segerson and Squires 1990; Vestergaard et al 2003), because we consider the firm’s immediate response in terms of exit when the fixed factors are constant.

The benchmark scenario in our model is business as usual (BAU), under which management continues in the form of nontransferable individual vessel quotas (IVQ). The firm’s decision is dictated by the net present value (NPV), and the buyout is chosen if the payment is at least as high as the opportunity cost comprised of the sum of discounted profits from remaining in the fishery. The second scenario reevaluates the NPV, assuming that the firm expects to trade its quota at the market price in the future. This scenario introduces ITQs. With the expected quota trade, the the expected profit from ownership of quota is capitalized into the NPV (Grainger and Costello 2014). The expected profit from tradable permits is also capitalized into other inputs with inelastic supply (Wossink and Gardebroek 2006) as a quasi-rent, affecting demand for the harvest of other unregulated species.

The paper derives a method to evaluate whether fishery participants anticipate policy change in a given setting by analyzing their revealed behavior. It contributes to the literature by showing that the fleet profit structure that implies asymmetric demand for tradable quota has considerable implications on how the buybacks are designed and executed. The paper presents empirical evidence of fishermen’s strategic behavior and acting upon expectations regarding policy change. As Nøstbakken et al (2011) note, there is a particular need for additional empirical work on investment and disinvestment drivers at the firm level based on appropriate economic data. Vessel buybacks can lead to very different numbers of exits depending upon the production structure of the fleet (Graff-Zivin and Mullins 2015), and as this paper shows, also depending upon expectations and accompanying policy instruments. How well this production structure is understood will guide the accuracy of the predicted outcomes.

The empirical case study of the Polish cod trawler fishery in the Baltic Sea, utilizing a unique dataset, illustrates the misleading results that arise due to myopic expectations and the accurate results due to accurately formed expectations throughout a modeling exercise (Clark et al 2007). Currently held IVQs may have a sufficiently high opportunity cost to alter firm behavior if the expectations of quota tradability are high (Weninger and Just 1997). However, the capitalization value depends on the expected time frame of the policy change and production flexibility, the extent of which is an important aspect of analyzing fleet adjustment to new regulations. We compare scenarios that vary by the time frame over which policy change is introduced with the actual situation at the end of the time-limited buyback available to the fishing vessel
We observe that the government speculations on possible management change to allow quota tradability, by impacting expectations, apparently led fewer vessels to exit than expected under the presumption that BAU status of non-transferability would be maintained. We find that the capitalized value of quota is not the sole reason. Carefully evaluating the profit structure of the fleet, we conclude that substitutability between regulated and unregulated species (Hutniczak 2014) would be capitalized through specializing in alternative production, and therefore crucial for drawing conclusions on disinvestment incentives.

The model setup is flexible, and accounts for a complicated harvest process that involves multispecies production, combining the exploitation of regulated and unregulated stocks. The analysis examines which vessels will remain in the fishery and which will discontinue harvest of the initial main target species. Moreover, the analysis accounts for the multi-gear nature of the fishing industry, and allows for gear switching over the course of the year, which is often disregarded in modeling (Bockstael and Opaluch 1983). The model also accommodates nonlinearities in the harvest cost of the main target species.

The paper is structured as follows. Section 2 introduces the model of fishing firm behavior under non-transferable and transferable individual quotas. Section 3 provides insights to the case analyzed and the available data, while Section 4 presents the model results. The paper closes with conclusions regarding the expected implications of a policy change anticipation and general recommendations for fisheries management.

2 Materials and methods

2.1 Model of Firm Behavior

The behavior of a firm that is subject to restrictions can be described by a partial static equilibrium model (Diewert 1973; Lau 1976). The firm maximizes its restricted profits \( \pi^r(P;Z) \) by selecting levels of unrestricted variable netputs (inputs \( x_i < 0, i \in I_{in} \) and outputs \( x_i > 0, i \in I_{out} \), \( X = x_i, i \in I = I_{in} + I_{out} \)), while facing restrictions introduced by a vector of fixed factors \( Z \) (inputs \( z_j < 0, j \in J_{in} \) and outputs \( z_j > 0, j \in J_{out} \), \( Z = z_j, j \in J = J_{in} + J_{out} \)). Conventionally, restricted netputs include quasi-fixed physical capital that we index with \( k \) (\( k \in J_{in} \)). Restricted netputs may also include outputs in the case of strictly binding quota. The firm is in partial static equilibrium conditional upon \( Z \) and \( P \) (\( P = p_i, i \in I \)), the vector of variable netput prices. Let \( \pi^r_Z(P;Z) = W^* \) denote the vector of shadow prices of \( Z \), where \( \pi^r_Z(P;Z) \) denotes the vector of first partial derivatives with respect to elements of \( Z \). When \( Z \), and hence the otherwise unrestricted profit function, is in full static equilibrium, \( W^* = W \), where \( W = w_j, j \in J \) denotes a vector of market prices for quasi-fixed or fixed netputs. When a single netput \( z_j \) is in full static
equilibrium, $\partial \pi^r / \partial z_j = w^*_j = w_j$. $W$ includes capital services or market rental prices for physical capital and market prices for other netputs that levels are externally constrained, e.g. by regulations.

Assuming competitive price taking behavior, and therefore exogenous prices of variable netputs $P$, the total profit function is (Squires 1988):

$$ H(P; Z, W) = \max_{X} \{ P^\top X; (X, Z) \in T \} + \sum_{j \in J} w_j z_j $$

$$ = \pi^r(P; Z) + \sum_{j \in J} w_j z_j. \quad (1) $$

$T$ is the restricted production possibility set, assumed to be nonempty within its domain, closed, convex, bounded and monotonic. Equation (1) gives total profit that can differ from the firm’s full static equilibrium profit unless each $z_j$ is at its full static equilibrium level, in which case (1) is a full static equilibrium profit function and $W^* = W$ (Diewert 1974; Lau 1976). To be consistent with long-run profit maximization, second-order conditions for $Z$ are those of quasi-concavity (Diewert 1974; Lau 1976). By Hotelling’s lemma:

$$ x_i(P; Z) = \frac{\partial \pi^r(P; Z)}{\partial p_i}, \quad (2) $$

where $x_i(P; Z) > (<) 0$ for $i \in I_{\text{out}}$ ($i \in I_{\text{in}}$) represents a short-run or partial static equilibrium output supply (input demand) function for variable netput $i$.

Consider an open-access fishery with an unrestricted harvest (but restricted by other factors $Z$, e.g. physical capital stock) becoming subject to constraining management on one of the variable outputs, say species $i$. Denote this previously unregulated variable output $x_i$ now regulated by a binding quantity control as $q_i$, where $q_i < x_i$ for $i \in I_{\text{out}}$. One option is an individual non-transferable quota. The firm’s restricted profit function additionally constrained by $q_i$ is written (Fulghini and Perrin 1993):

$$ \pi^c(P; q_i, Z) = \pi^r(P^{-i}; q_i, Z) + p_i q_i. \quad (3) $$

Here, $\pi^r(P^{-i}; q_i, Z)$ denotes the firm’s partial profit function independent of price $p_i$, where $P^{-i}$ indicates the vector of netput prices excluding price $p_i$. The partial profit function shares the properties of the restricted profit function unconstrained by $q_i$ appearing in equation 1. It assumes full utilization of a given quota, which is assured by a positive shadow value of quota ($\pi^c_{q_i}(P; q_i, Z) > 0$) or otherwise full utilization has to be forced. Adding an additional output constraint, the firm’s total profit function becomes:

$$ II(P; q_i, Z, W) = \pi^r(P^{-i}; q_i, Z) + p_i q_i + \sum_{j \in J} w_j z_j. \quad (4) $$

Recall that if $q_i$ was already a regulated output, it would comprise an element of $Z$, and its price would form a part of $W$. But if $q_i$ was previously unregulated, after imposing binding quota, $q_i$ would be considered an element added
to $Z$ with its price shifted to vector $W$.

The price that would cause the firm to produce an optimal level of a previously unregulated netput equal to that specified in the regulation is called the virtual price (Rothbarth 1941; Neary and Roberts 1980). If the actual output price exceeds the virtual price, the vessel produces below its private unconstrained economic optimum, whereas if the actual output price is lower, production is forces, and private rational behavior dictates decreasing the harvest scale with respect to species $i$. The virtual price $\phi_i$ for $q_i$ is implicitly defined as the solution to: $$ q_i = \frac{\partial \Pi(\phi_i, P^{-i}; Z)}{\partial \phi_i}. $$ From this, $\Pi(P; q_i, Z) = \Pi(\phi_i, P^{-i}; Z) + (p_i - \phi_i)q_i$. $\tau_i = p_i - \phi_i$, the unit rent corresponding to $q_i$ facing $\phi_i$ to produce the same as under $q_i$. $\tau_i = p_i - \phi(P; q_i, Z)$ forms the equilibrium inverse derived demand function for $q_i$, which is an equilibrium function that takes into account the total optimal adjustment of all variable inputs and outputs given prices, quasi-fixed factors, and technology (Squires and Kirkley 1996; Vestergaard 1999).

2.2 Exit incentives

The profit-maximizing production decision of the firm in the fishing sector can be considered as a two-stage process (Lau 1976). In the first stage, the firm maximizes restricted profit by producing outputs (restricted and unrestricted) at a predetermined level of both physical and natural capital stocks that is fixed in the short run but variable in the long run given the state of technology. In the second stage, the vessel owner faces the decision regarding investment or disinvestment. The vessel’s long-run, profit-maximizing equilibrium in the physical capital stock, conditional upon natural capital stock and technology, is achieved by optimally adjusting quasi-fixed physical capital, which requires $w_k = w^*_k (k \in J_{on})$, as discussed above. However, the fundamental parameters of the vessel determining the main harvest decisions are not easily adjustable. This includes, for example, a size that specifies the range of distances to the fishing grounds and maximum loading during a single trip. In order to change these parameters, a new vessel is typically bought or major overhauling and refitting are required. Thus, assuming considerable differences in replacement cost comparing to owned capital value, restrictions regarding new entrants, and focus on immediate incentives created by buyback, we consider the disinvestment decision only in terms of exit from the fishery, conditional upon the natural capital stock, technology, and overall decadal-scale state of the environment.

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2 For profits conditional on owned capital $z_k$ and quota $q_i$, the shadow price, as noted earlier, is $w^*_k = \frac{\partial \pi^*_{r}(P^{-i}; q_i, z_k)}{\partial z_k}$. When $w^*_k = w_k$, the firm’s profit function constrained by $z_k$ and $q_i$ (equation 4) is indistinguishable from the firm’s profit function unconstrained by all netputs but $q_i$. 

The exit incentives, created by the introduction of a buyback program offering a single payment for removing the physical capital from the industry, are now considered. The optimal choice can be obtained by examining the firm’s NPV of expected future profits that are maximized in a given policy setting (Vestergaard et al. 2005) in comparison with the available decommission payment. The vessel is assumed to have no salvage value as the opportunity cost is negligible in comparison to the available scrapping payment. This means that we assume that the purchase price is a sunk cost unless the vessel uses the buyback.\(^3\) The annual profit of an active vessel is the sum of restricted profits and revenue from harvest of a given non-transferable quota, reduced by annual fixed costs, \(w_k z_k\), conditional on operating.\(^4\) The NPV of the flow of benefits simplified to include one fixed or quasi-fixed input in the form of physical capital stock \(z_k\) that is priced \(w_k\), can be calculated given the expected time of vessel exploitation \(t_{ex}\) as:

\[
\Omega_{IVQ} = \sum_{t=0}^{t_{ex}} \rho^t (\pi^{-1}(P_i, q_{i,t}, z_k) + p_i q_{i,t} + w_k z_k),
\]

where \(\rho\) indicates a positive private discount rate, prices are constant over time, and \(t\) denotes time. This sum can be compared with the alternative benefit in the form of total buyback compensation \(\Psi(z_k)\), which is a function of physical capital (details in subsection 3.1). \(\Omega_{IVQ} > \Psi(z_k)\) implies insufficient payments available for attracting the vessel to enter the decommissioning program, whereas \(\Omega_{IVQ} < \Psi(z_k)\) implies positive exit incentives and vessel retirement. We can also solve equation 5 for the minimum time horizon over which the vessel has to be utilized to be indifferent between two options for a given \(\rho\). The solution presents incentives under BAU and myopic expectations regarding quota trade in the future.

Consider next a firm with a rational expectation of the introduction of the ITQ system for species \(i\). The exit incentives created by a buyback program are shifted by a possibility of annual quota trade at the market lease/rental price (Vestergaard et al. 2005).\(^5\) In this case, the firm’s NPV of the flow of

\(^3\) The sunk cost is defined following Vestergaard et al. (2005) as \(s - S\), where \(s\) denotes the purchase price, \(S\) denotes the salvage value, and where \(s \geq S \geq 0\). This specification is reasonable in a fishery with excess capacity and over-capitalization with few or no opportunities to enter into other fisheries - precisely the conditions under which buybacks are implemented.

\(^4\) The price \(w_k\) includes all non-variable, effort-level independent fixed costs conditional on positive utilization of capital (that is, \(w_k = 0\) if vessel exits), such as annual insurance payments (that may be zero or below insured market value), dockage fees, license fees, etc. Note that \(w_k\) excludes capital interest as it has to be paid regardless of the exit decision. Therefore, it is irrelevant for our comparison with buyback payment.

\(^5\) Note that the exit decision includes not just the decision to disinvest the physical capital stock, but also includes the decision to disinvest the quota holdings (Weninger and Just 1997; Vestergaard et al. 2005).
benefits is:

\[ \Omega^{ITQ} = \sum_{t=0}^{l} \rho^t \left( \pi^t_i(\mathbf{P}^{-1}, \phi^0_i; z_k) + (\phi^0 - \phi^0_i)q_{i,t} + \omega_k z_k + \tau_{i,t}(1 - \alpha_{i,t})q_{i,t} \right), \]

where \( \pi^t_i(\mathbf{P}^{-1}, \phi^0_i; z_k) \) is the partial profit evaluated at virtual price for species \( i \), \( (\phi^0_i - \phi^0)\alpha_{i,t}q_{i,t} \) is the harvest rent, \( \omega_k z_k \) is the fixed cost, and \( \tau_{i,t}(1 - \alpha_{i,t})q_{i,t} \) is rent for the allocation traded and valued at the market price. Furthermore, \( \alpha_{i,t} \) indicates share of individual initial quota allocation at time \( t \), \( q_{i,t} \), which the unit decides to harvest, where \( \alpha_{i,t} \geq 0 \). When \( \alpha_{i,t} = 0 \), the quota species, as a non-essential product of the firm, is not produced. Conversely, \( \alpha_{i,t} \in [0, 1] \) implies sale of quota on the competitive secondary market for ITQs and \( \alpha_{i,t} > 1 \) implies purchase of additional quota. \( \phi^0 \) denotes the virtual price corresponding to harvest of \( \alpha_{i,t}q_{i,t} \). Note that \( \alpha_{i,t} \) is a decision parameter indicating direction of trade. Thus, \( \pi^t_i(\mathbf{P}^{-1}, \phi^0_i; z_k) + (\phi^0_i - \phi^0)\alpha_{i,t}q_{i,t} \) captures the total harvest profit with production of \( i \) equal to \( \alpha_{i,t}q_{i,t} \), whereas term \( \tau_{i,t}(1 - \alpha_{i,t})q_{i,t} \) indicates transaction value. If \( \alpha_{i,t} > 1 \), it is the cost of additional quota purchase. Conversely, if \( \alpha_{i,t} \in (0, 1) \), it is the financial profit from selling \( 1 - \alpha_{i,t} \) share of initial individual quota allocation \( q_{i,t} \). If \( \alpha_{i,t} \neq 1 \), trade occurs at the competitive ITQ market price \( \tau_{i,t} \). The alternative option is to wait for the ITQ introduction and, once the new management scheme is in place, sell quota permanently and exit. The expected value of quota permanently sold equals the NPV of the annual lease price of the allocated resource. Here, we follow Asche (2001), who notes that the first few years comprise a large proportion of the quota value, and assumes that fishers assign value to the harvesting right over a limited time horizon equal to the vessel’s lifetime.

The market price \( \tau_{i,t} \) is endogenously determined in the model at the industry level. Asymmetries between vessels in unit quota rents, the result of differentiating equation 4, present a potential for quota trade that manifests in equation 6 under the value of \( \alpha_{i,t} \). Introducing ITQs facilitates exchange, in which vessels with higher shadow value of quota, i.e. unit quota rent, have an incentive to purchase additional quota from vessels with lower shadow value of quota: \( (\phi^0_i - \phi^0)\alpha_{i,t} \neq (\phi^0_r - \phi^0)\alpha_{i,t} \), where \( r, m \in R \) index the individual firms and \( R \) denotes the total number of firms in the fishery, \( r \neq m \). Moreover, \( (\phi^0_i - \phi^0) > (\phi^0_r - \phi^0) \) indicates economic incentives to purchase (sell) quota until in equilibrium at the margin \( (\phi^0_i - \phi^0)\alpha_{i,t} = (\phi^0_r - \phi^0)\alpha_{i,t} \) \( \forall r, m \in R \), by the equi-marginal principle. Such exchange creates arbitrage efficiency, and the quasi-rent is comprised of quota income and quota surplus (Anderson 1988; Squires and Kirkley 1996; Vestergaard 1999). We assume that all ITQs enter the competitive secondary market or are bilaterally exchanged at the secondary market price and that the quota supply is limited to the initial allocation, i.e. \( \sum_{i \in R} \alpha_{i,t}q_{i,t} = \sum_{i \in R} q_{i,t} \). Consequently, in the case without trade, the capital buyout incentives depend on the quota shadow value of the individual vessel, whereas in the case with trade, it is the shadow value of the
more efficient vessels that are willing to pay for additional quota that drives the exits.

2.3 Empirical model

We specify a symmetric normalized quadratic profit function (SNQPF) (Diewert and Wales 1987). The choice in this case is dictated by the possibility of a negative restricted profit in the data set, and therefore the standard translog functional form is not appropriate. The partial profit ($\pi^r$) of the total constrained profit function (equation 4) for each individual unit takes the form:

$$
\pi^r(P; Z) = \sum_{i \in I} \alpha_i p_i + \frac{1}{2} \left( \sum_{i \in I} \theta_i p_i \right)^{-1} \sum_{i \in I} \sum_{i' \in I} \alpha_{ii'} p_i p_{i'} + \\
\frac{1}{2} \left( \sum_{i \in I} \theta_i p_i \right) \sum_{j \in J} \sum_{j' \in J} \alpha_{jj'} z_j z_{j'} + \sum_{i \in I} \sum_{j \in J} \alpha_{ij} p_i z_j + \\
\frac{1}{2} \left( \sum_{i \in I} \theta_i p_i \right) \sum_{j \in J} \sum_{j' \in J_{out}} \alpha_{jj'} z_j z_{j'}^2 + \left( \sum_{i \in I} \theta_i p_i \right) \sum_{t \in T} \alpha_t D_t.
$$

Here, $p_i, p_{i'}$ are the prices of netputs $i$ and $i'$; $i, i' \in I$, $z_j, z_{j'}$ are quasi-fixed netputs, including species regulated by IVQ (quasi-fixed outputs) and capital (quasi-fixed input), $j, j' \in J$, $D_t$ are a set of dummies controlling for stock size and changes in regulations, environment, and technology, $\sum_{i \in I} (p_i \theta_i)$ is a price index, and $\theta_i$ are weights of prices. Additionally, as the primary interest here is on output regulations, additional coefficients representing quadratic marginal products are introduced, yielding $z_j^2, j' \in J_{out}$. The symmetry of the SNQPF is imposed by restrictions on the parameters of the form: $\alpha_{ii'} = \alpha_{i'i}$ and $\alpha_{jj'} = \alpha_{j'j}$ and linear homogeneity in prices by normalization, in this case using the price index. The SNQPF permits the estimation of parameters from input demand and output supply equations using actual quantities, where $x_i(P; Z) >$

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6 The profit function is specified with a quadratic functional form as a second-order Taylor’s series approximation around the unit price vector in base period. All prices are scaled such that their mean in 2008 is one.

7 The weights are obtained using method presented by Diewert and Wales (1992): $\theta_i = |x_i| p_i^0 / \sum_{i' \in J} |x_i| p_i^0$, where $p_i^0$ is average price of netput $i$ in the base period.
Using Hotelling’s Lemma yields:

\[
x_i(P; Z) = \frac{\partial \pi^r}{\partial p_i} = \alpha_i + \left( \sum_{i' \in I} \theta_{i'i'} p_{i'} \right)^{-1} \sum_{i' \in I} \alpha_{ii'} p_{i'} -
\]

\[
\frac{1}{2} \theta_i \left( \sum_{i' \in I} \theta_{i'i'} p_{i'} \right)^{-2} \sum_{i' \in I} \sum_{i'' \in I} \alpha_{i'i''} p_{i'} p_{i''} +
\]

\[
\frac{1}{2} \theta_i \sum_{j \in J} \sum_{j' \in J} \alpha_{jj'} z_j z_{j'} + \frac{1}{2} \theta_i \sum_{j \in J} \sum_{j' \in J_{out}} \alpha_{jj'} z_j^2 +
\]

\[
\sum_{j \in J} \alpha_{ij} z_j + \theta_j \sum_{\ell \in T} \alpha_{\ell} D_{\ell},
\]

The additive errors, assumed contemporaneously correlated, are appended to each equation. The system of input demand and output supply equations is estimated by Seemingly Unrelated Regression (SUR). The production process is analyzed in terms of separability and non-jointness, with details given in appendices A and B.

2.4 Model setup

The model allows analyzing the rational decision-making and incentives created by the buyback scheme under different expectations regarding future quota management. The model assumes strict entry/exit regulations currently in place\(^8\) that allow either permanent exit or entry of a new firm preceded by the exit of a similar vessel. Thus, the physical capital stock is assumed fixed in terms of vessel size and quasi-fixed in terms of activity, facing a medium-term disinvestment decision only in terms of staying in the fishery without reinvestment or exit.\(^9\) Such an approach is particularly valid in a situation in which the capital value is considerably lower than the replacement cost, i.e. the difference between utilization of existing capital and investment in a new vessel is high.

The model assumes scrapping payments are available only at the initial time period \((t = 0)\) and that there are two scenarios regarding the anticipation of introducing ITQs in the near future. In the first scenario, the vessel owner makes a decision regarding the vessel’s activity, assuming continuation of the current IVQ system where in which no quota trade is allowed (BAU scenario). In the second scenario, quota trade of is anticipated in the near future (ITQ scenario). The competitive quota price is determined at the industry level as vessels exchange their quotas until the last unit is traded and

\(^8\) The entry-exit regime in EU is based on Article 13 of Council Regulation 2371/2002 and Articles 6 and 7 of Commission Regulation 1438/2003.

\(^9\) Medium-term perspective is more than a single season, but not the infinite time horizon. For the present consideration, this could be thought as one-owner decision perspective.
the market price equilibrating the unit quota rents across vessels at the margin is formed through the equi-marginal principle, as discussed above. We also assume the initial quota is annually allocated to vessel owners free of charge, i.e. grandfathered *gratis*. In the analysis, created incentives are calculated as the expected composition of exits with respect to initial fleet size. The changes induced by potential quota trade are calculated for the ITQs’ anticipation in the first time period after scrapping \((t = 1)\). The choice of \(t = 1\) gives a range of solutions for the anticipation of the ITQ at any \(t > 1\) when comparing with BAU that can be considered a solution for \(t = \infty\). The model in its deterministic form assumes a modest real discount rate \(\rho\) of 4% for individual fishing firm. Although the uncertainty, especially regarding the future quota allocations, could motivate setting the discount rate higher, the comprehensive and well-functioning quota system currently in place suggests that fishermen should not be too shortsighted in their decisions. The results for two scenarios, BAU and ITQ, are derived for harvest amounts equal to the quotas within the expected range of future total allowable catch (TAC).

3 The Data

3.1 Background of the case

The Baltic Sea cod \((Gadus morhua)\) is the most valuable species for the Polish fleet (generating approximately 34% of revenue\(^{10}\)). Two other important target species include sprat \((Sprattus sprattus)\) and herring \((Clupea harengus)\), generating approximately 24% and 17% of total revenue, respectively. The Baltic Sea cod consist of two separate stocks, eastern and western, with the western stock of minor importance for Poland.\(^{11}\) The abundance of the eastern cod stock has fluctuated substantially since the 1960s (figure 1). Peak biomass reached in the 1980s, over a million tons, is attributed to the high frequency of inflows from the North Sea that resulted in good spawning conditions and recruitment quality. At the time, the Baltic Sea cod catch accounted for approximately 21% of worldwide landings of this species. The increase in fishing pressure on the stock in the following years, with landings of nearly 400 000 t per year (1984) due to improvements in technology and increased fishing effort (Bagge et al 1994), caused the biomass to drop below the biological limit, the level potentially threatening the self-renewal capacity of the stock (Rockmann et al 2005). While a 1993 water inflow improved the egg survival rate, limited food supply prevented a noticeable change in the size of the stock, which reached its lowest recorded level in 2005.

Overcapacity in the Polish fishing fleet is considered an ongoing problem, mainly in the cod fishery. The first comprehensive, long-term management plan for cod was the Long-Term Management Strategy for Cod Stocks in the

\(^{10}\) Revenue shares based on average 2008-2010 data from STECF (2012).

\(^{11}\) On average approximately 7% of the cod catch over the period 2008-2010.
Baltic Sea (1999). The key objective, maintaining fishing within limits that do not impair reproduction, forms the main principal of the precautionary approach (Hoydal 1983). The follow-up plan, the Recovery Plan for the Baltic cod (2001), in addition to reviewing desired fishing mortality, introduced seasonal and area closures (Aps and Lassen 2009). In 2007, the European Union Council established the latest management plan for the cod stocks in the Baltic Sea and the fisheries exploiting those stocks (EC 1098/2007). The plan, in addition to technical regulations restricting the harvesting process, redesigned procedures for setting cod TAC from 2008.

Poland, a member of the EU since 2004, has been obligated to comply with the imposed cod TAC since 2005. The government executed the total cod harvest restriction by allocating IVQs based on vessel length class, initially for vessels over 10m (table 1). However, quotas decreasing over years resulted in a series of fishermen’s protests. The 2007 harvest reduction was not enforced, causing the final catch to significantly exceed the given limit. As 2008 was supposed to start the new restrictive management plan (EC 1098/2007), Poland was penalized by an additional TAC reduction equal to the total excess amount harvested. The total penalty was distributed over the next four years such that the assigned quota was reduced by 10% of the excess in 2008 and by 30% of the excess each year in the period 2009-2011. As a result, the expected quota for individual vessels in upcoming years was small and potentially insufficient to ensure the continued profitability of numerous fishing firms. Therefore, an alternative allocation system was introduced for the 2009-2011 period. This unique scheme only allowed roughly one-third of the vessels to continue harvesting cod in a given year, with lottery determining the eligible vessels. Participants holding cod harvest permits in 2005 were only allowed to receive a quota once over this three-year period (summary in table 2). Each year, the remainder of the fleet that did not obtain quotas received direct subsidies as compensation for temporarily suspended fishing activity. The payments were based on remaining in port for a minimum of 120 days, whereas these vessels were allowed to fish for other species the rest of the year. Consequently, merely one-third of the fleet harvested 70% of the regular TAC (30% reduction due to the described penalty). This is considered here a well-established sign of overcapacity. Targeting this problem, the "Sustainable

---

**Fig. 1** Change in Total Stock Biomass of Baltic Sea cod (1966-2012) (ICES 2014).
Table 1  Comparison of cod IVQ (2008-2012).

<table>
<thead>
<tr>
<th>Year</th>
<th>8-11.99m</th>
<th>12-14.99m</th>
<th>15-18.49m</th>
<th>18.5-20.49m</th>
<th>20.5-24.99m</th>
<th>≥25.5m</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>NA²</td>
<td>21.0 t</td>
<td>41.9 t</td>
<td>29.4 t</td>
<td>8.4 t</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>55 t</td>
<td>65 t</td>
<td>85 t</td>
<td>90 t</td>
<td>102.5 t</td>
<td>70 t</td>
</tr>
<tr>
<td>2010</td>
<td>55 t</td>
<td>65 t</td>
<td>85 t</td>
<td>90 t</td>
<td>102.5 t</td>
<td>70 t</td>
</tr>
<tr>
<td>2011</td>
<td>55 t</td>
<td>65 t</td>
<td>85 t</td>
<td>90 t</td>
<td>102.5 t</td>
<td>70 t</td>
</tr>
<tr>
<td>2012</td>
<td>42.1 t</td>
<td>52.6 t</td>
<td>61.1 t</td>
<td>59.3 t</td>
<td>16.5 t</td>
<td></td>
</tr>
</tbody>
</table>

1 3-year lottery plan
2 Common pool quota

Table 2  Number of vessels with special permits for harvesting cod (2008-2012).

<table>
<thead>
<tr>
<th>Year</th>
<th>8-11.99m</th>
<th>12-14.99m</th>
<th>15-18.49m</th>
<th>18.5-20.49m</th>
<th>20.5-24.99m</th>
<th>≥25.5m</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>219</td>
<td>54</td>
<td>94</td>
<td>11</td>
<td>49</td>
<td>54</td>
<td>481</td>
</tr>
<tr>
<td>2009</td>
<td>86</td>
<td>17</td>
<td>30</td>
<td>4</td>
<td>15</td>
<td>16</td>
<td>166</td>
</tr>
<tr>
<td>2010</td>
<td>87</td>
<td>18</td>
<td>26</td>
<td>4</td>
<td>15</td>
<td>16</td>
<td>166</td>
</tr>
<tr>
<td>2011</td>
<td>132</td>
<td>27</td>
<td>22</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>204</td>
</tr>
<tr>
<td>2012</td>
<td>248</td>
<td>53</td>
<td>65</td>
<td>13</td>
<td>33</td>
<td>32</td>
<td>444</td>
</tr>
</tbody>
</table>

1 3-year lottery plan

Fig. 2  Scrapping payments available to Polish fishing vessel owners in 2009 [PLN, 2008].

development of fishery sector and coastal fishery areas” program (budget of EUR 225 million) was introduced to adapt the fleet to the available resources. It reinforced permanent exit of vessels from the fishery by providing payments for vessel scrapping or transitioning to a non-fishing business. In the period 2009-2011, 72 out of 832 vessels were removed from the fleet with a use of public funds (Karnicki 2012). Figure 2 presents a summary of available buyback payments based on vessels’ tonnage.

3.2 Data description

The empirical application, based on a unique dataset, combines various sources of data. Parameters of vessels and netput quantities aggregated over a year are based on logbook data available through the Polish Fisheries Monitoring
The detailed harvest volumes are based on reported Baltic Sea landings (kg of fresh weight) in the 2008-2010 period for each main species separately. The harvest of species other than cod, herring, and sprat was linearly aggregated. This study, due to its interest in the cod fishery, focuses on trawlers with cod harvest permits (approximately half of the fleet above 10 m, 177 units active in 2008). Here, trawler is defined as a vessel using trawling gear as a main fishing gear during at least one-half of its fishing time. The study is limited to vessels over 10 m, as smaller vessels were not subject to IVQs during the whole analysis period and could not be analyzed using the method described in Section 2. The median age of a trawler in the Polish fleet is 35 years with quantile range of 28 to 45 years.

The input measure was operationalized as the power of the main engine multiplied by the number of hours at sea (kWday unit, day as 24 hours at sea) to give a flow of services and divided into categories according to the type of the trawling gear. The measure provides a good approximation for calculating the variable costs for trawlers in contrast to other gears. Thus, such a proxy for effort divided into two categories based on the type of trawling gear, demersal and pelagic, is considered here as two separate inputs. Marginal use of other types of gear (<2%), mostly including gillnets, is excluded.

Output prices were based on average monthly fish unloading prices from the two main Polish ports, Kolobrzeg and Władysławowo, provided by the Polish Marine Institute in Gdynia. Landings outside of a typical season or during closure were assigned the minimum annual price. The landings of other species were assigned the price of European flounder (Platichthys flesus), which constituted about 97% of the other species harvest.

Input prices were based on the yearly mean price of a kWday unit of effort for each type of trawling within engine power category (every 50 kW). Values were derived from the sample of annual cost reports submitted to the Polish

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12 FMC in Gdynia is a branch of the Fisheries Department within the Ministry of Agriculture and Rural Development in Warsaw. The individual vessel data is confidential and cannot be shared by authors without further aggregation.

13 Landings of salmon, sea trout and rainbow trout are reported in a number of individuals. These values are converted to weight according to the mean weight per individual in the Polish harvest.

14 OTB, PTB, OTM and PTM in accordance to abbreviations provided by the International Standard Statistical Classification of Fishing Gear (FAO 1997).

15 The fleet structure in terms of size, age and main gear is available from European Commission Fleet Register: http://ec.europa.eu/fisheries/fleet/.

16 Trawlers conduct an active type of fishing requiring constant movement in order to chase the targeted fish. Thus, costs are closely correlated to time at the sea. In contrast, passive gear is set in the water for certain time period and time at the sea do not necessarily reflect the variable cost. This unit of effort is also one of the indicators used by the Baltic Fisheries Assessment Working Group in ICES reports (ICES 2014).
The input prices cover all the variable costs including fuel, labor, maintenance, and other miscellaneous variable costs. In addition, gear costs were included, since fully functioning gear is required to fish, and the economic lifetime of many types of gear is short due to high rates of physical depreciation. Leontief separability between cost components was assumed.\textsuperscript{18} Moreover, the reports allow the derivation of the fixed costs values. All prices were deflated to 2008 PLN; the year 2008 was also chosen as the base year for scaling the variables. The final data set consisted of 434 trawler/year observations. Additionally, FMC provided information on which of the vessels included in the dataset remained in the fishery in 2012.

### 3.3 Model inputs

Table 3 presents the arithmetic means of the restricted profit function variables used in the estimations. The summary statistics, provided separately for 2008 and 2009/2010, show differences between management regimes. Here $p_c$ indicates the landing price of cod, $p_h$ the landing price of herring, $p_s$ the landing price of sprat, $p_o$ the landing price of linearly aggregated other species, $p_d$ the price of kWday using demersal trawl gear, $p_p$ the price of kWday using pelagic trawl gear, $z_k$ is a capital input in the form of the vessels’ tonnage, $y_q$ the cod quota quantity, $y_h$ the herring harvest, $y_s$ the sprat harvest, $y_o$ the harvest of other species, $y_d$ the kWday of demersal gear use, $y_p$ the kWday of pelagic gear use, and $w_k$ the fixed cost per GT of capital input. The two scenarios described, BAU and ITQ, are evaluated for quotas equal to individual allocations after the TAC reduction penalty was phased out, i.e. individual quotas from 2012 (table 1).

### 4 Results and discussion

#### 4.1 Model estimates

Table 4 presents the estimated coefficients of the restricted profit function together with bootstrapped cluster robust standard errors and p-values. Appendix C gives details on the estimation procedure. Most coefficients are significant at the 95% confidence level, indicating good data fit. The $R^2$ of the individual equations are 0.33, 0.34, 0.05, 0.29 and 0.65 for the harvest of herring, sprat, other species, the input of demersal trawl and pelagic trawl, respectively. The whole system goodness of fit, measured by McElroy’s $R^2$, is 0.35.

\textsuperscript{17} Individual vessels’ reports are confidential, cannot be directly combined with log book data, and are obtained through personal communication with Emil Kuzebski.

\textsuperscript{18} The correlation coefficients based on available data were as follows: fuel cost and labor cost: 0.79, fuel cost and other costs: 0.72, labor cost and other costs: 0.67.
Table 3 Mean and standard deviation of the restricted profit function variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean 2008</th>
<th>SD 2008</th>
<th>Mean 2009/10</th>
<th>SD 2009/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod price per kg [PLN, 2008]</td>
<td>$p_c$</td>
<td>5.69</td>
<td>0.34</td>
<td>5.22</td>
</tr>
<tr>
<td>Herring price per kg [PLN, 2008]</td>
<td>$p_h$</td>
<td>1.13</td>
<td>0.09</td>
<td>1.16</td>
</tr>
<tr>
<td>Sprat price per kg [PLN, 2008]</td>
<td>$p_s$</td>
<td>0.54</td>
<td>0.04</td>
<td>0.55</td>
</tr>
<tr>
<td>Other species price per kg [PLN, 2008]</td>
<td>$p_o$</td>
<td>1.68</td>
<td>0.17</td>
<td>1.53</td>
</tr>
<tr>
<td>Price of kWday using demersal trawl gear [PLN, 2008]</td>
<td>$p_d$</td>
<td>19.26</td>
<td>6.65</td>
<td>20.11</td>
</tr>
<tr>
<td>Price of kWday using pelagic trawl gear [PLN, 2008]</td>
<td>$p_p$</td>
<td>22.77</td>
<td>1.65</td>
<td>20.98</td>
</tr>
<tr>
<td>Vessel’s tonnage [GT]</td>
<td>$z$</td>
<td>87.13</td>
<td>58.87</td>
<td>86.89</td>
</tr>
<tr>
<td>Cod harvest [t]</td>
<td>$q$</td>
<td>26.58</td>
<td>16.07</td>
<td>59.22</td>
</tr>
<tr>
<td>Herring harvest [t]</td>
<td>$x_h$</td>
<td>88.03</td>
<td>175.95</td>
<td>162.84</td>
</tr>
<tr>
<td>Sprat harvest [t]</td>
<td>$x_s$</td>
<td>314.25</td>
<td>623.58</td>
<td>537.45</td>
</tr>
<tr>
<td>Harvest of other species [t]</td>
<td>$x_o$</td>
<td>33.12</td>
<td>51.22</td>
<td>55.64</td>
</tr>
<tr>
<td>Demersal trawl input [1000<em>kW</em>day]</td>
<td>$x_d$</td>
<td>9.22</td>
<td>8.41</td>
<td>7.95</td>
</tr>
<tr>
<td>Pelagic trawl input [1000<em>kW</em>day]</td>
<td>$x_p$</td>
<td>9.39</td>
<td>15.85</td>
<td>14.77</td>
</tr>
</tbody>
</table>

1 Prices of cod for gutted fish with head, the EU conversion factor for fresh fish is 1.17.
2 This is the full sample average, which includes numerous zeros for vessels that were not allowed to fish cod in these years; the average cod catch among vessels eligible to harvest cod was 99.63t.

Table 4 Estimated restricted profit function coefficients.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
<th>SE</th>
<th>p-value</th>
<th>Coefficient Value</th>
<th>SE</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_h$</td>
<td>-77.26</td>
<td>23.67</td>
<td>0.00</td>
<td>$\alpha_{hq}$</td>
<td>-0.96</td>
<td>0.33</td>
</tr>
<tr>
<td>$\alpha_s$</td>
<td>-170.02</td>
<td>45.59</td>
<td>0.00</td>
<td>$\alpha_{hk}$</td>
<td>-2.85</td>
<td>0.40</td>
</tr>
<tr>
<td>$\alpha_o$</td>
<td>108.87</td>
<td>15.04</td>
<td>0.00</td>
<td>$\alpha_{qk}$</td>
<td>-2.54</td>
<td>0.01</td>
</tr>
<tr>
<td>$\alpha_p$</td>
<td>195.65</td>
<td>22.10</td>
<td>0.00</td>
<td>$\alpha_{dk}$</td>
<td>-4.96</td>
<td>0.66</td>
</tr>
<tr>
<td>$\alpha_{hp}$</td>
<td>155.81</td>
<td>150.64</td>
<td>0.00</td>
<td>$\alpha_{dq}$</td>
<td>-0.03</td>
<td>0.18</td>
</tr>
<tr>
<td>$\alpha_{hp}$</td>
<td>-133.01</td>
<td>110.15</td>
<td>0.07</td>
<td>$\alpha_{dp}$</td>
<td>-1.71</td>
<td>0.24</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>25.21</td>
<td>29.50</td>
<td>0.23</td>
<td>$\alpha_{dk}$</td>
<td>-0.54</td>
<td>0.23</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>-38.96</td>
<td>17.65</td>
<td>0.02</td>
<td>$\alpha_{dq}$</td>
<td>0.19</td>
<td>0.42</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>-9.95</td>
<td>61.48</td>
<td>0.23</td>
<td>$\alpha_{dq}$</td>
<td>6.01</td>
<td>0.47</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>-35.53</td>
<td>88.96</td>
<td>0.00</td>
<td>$\alpha_{dq}$</td>
<td>5.49</td>
<td>3.58E-02</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>-15.48</td>
<td>27.37</td>
<td>0.25</td>
<td>$\alpha_{dq}$</td>
<td>9.80E-03</td>
<td>5.68E-03</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>-30.94</td>
<td>16.02</td>
<td>0.02</td>
<td>$\alpha_{dq}$</td>
<td>3.37E-03</td>
<td>1.22E-02</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>19.07</td>
<td>49.08</td>
<td>0.37</td>
<td>$\alpha_{dq}$</td>
<td>-1.32E-04</td>
<td>1.13E-04</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>4.86</td>
<td>25.38</td>
<td>0.00</td>
<td>$\alpha_{dq}$</td>
<td>144.79</td>
<td>74.85</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>-14.58</td>
<td>15.55</td>
<td>0.15</td>
<td>$\alpha_{dq}$</td>
<td>223.63</td>
<td>69.26</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>0.00</td>
<td>20.84</td>
<td>0.39</td>
<td>$\alpha_{dq}$</td>
<td>97.78</td>
<td>13.27</td>
</tr>
<tr>
<td>$\alpha_{d0}$</td>
<td>-13.29</td>
<td>15.24</td>
<td>0.17</td>
<td>$\alpha_{dq}$</td>
<td>3.28</td>
<td>52.41</td>
</tr>
</tbody>
</table>

The profit structure estimates tested with the standard Wald test are reported in table 5. The test for input-output separability, equation A.1, rejects the null hypothesis, indicating that fishing firms make their optimal harvest decision together with the input decision and adjust their short-run harvest strategies depending on both variable input and variable output prices and levels of quasi-fixed netputs. Therefore, the total catch of unrestricted species and total effort cannot be treated as a composite output or input. Almost non-jointness in inputs (equation B.1) is rejected, which implies benefits in
Table 5 Production structure tests results.

<table>
<thead>
<tr>
<th>H0</th>
<th>Restrictions</th>
<th>F-value</th>
<th>P-value</th>
<th>Conclusion on H0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input-output separability</td>
<td>18</td>
<td>466.63</td>
<td>0.00</td>
<td>Rejected</td>
</tr>
<tr>
<td>Almost non-jointness in inputs</td>
<td>6</td>
<td>3.25</td>
<td>0.00</td>
<td>Rejected</td>
</tr>
<tr>
<td>Almost non-jointness in outputs</td>
<td>1</td>
<td>0.76</td>
<td>0.88</td>
<td>Accepted</td>
</tr>
</tbody>
</table>

combining the production of multiple species with a use of shared or quasi-public input. Non-rejection of almost non-jointness in outputs (equation B.2) implies no disadvantages in specializing in one type of trawling. However, restrictions in the form of quotas require a sequential use of different types of effort to utilize most profitably the capital capacity. Local monotonicity of the predicted demand and supply equations is verified by examining whether each equation has the correct signs (positive for outputs and negative for inputs) at average P and Z values (arithmetic mean) (Dievert and Wales 1992).

4.2 Evaluation of scenarios

The individual exit incentives under the buyback scheme accompanied by non-tradable quotas (BAU scenario) are calculated according to equation 5. The relatively high scrapping payment in the case of no anticipation of future profits from sold quota results in an immediate exit incentive for about 17% of the fleet (30 out of 177 vessels). Moreover, approximately 46% of the fleet (82 out of 177 vessels) would have to continue fishing to at least the year 2020 (over 12 years) to earn benefits equal to the available decommissioning payment, and these firms are also considered to have a positive exit incentive. In the BAU scenario, scrapping payments would attract all vessel size categories. The comparison of the initial trawler fleet (2008) and the expected fleet structure that would be active after the buyback is finished (BAU scenario), given the model’s assumptions, is presented in figure 3 as black and gray bars, respectively. The fleet structure here is based on length bins, as length is the basis for quota distribution in Poland.

The estimated 2008 unit quota rent averaged 1.53 PLN per kg of cod (bootstrapped cluster robust standard error 1.07 PLN). Hence, compared with the actual average cod price of 4.86 PLN per kg, the rent accounted for approximately 31% of revenue, which is consistent with the range of numbers found in the literature, e.g., Dupont (1990) or Asche et al (2008). However, while the cod fishery is on average profitable, the current situation is far from optimal. Based on estimated coefficients, figure 4 depicts the Marginal Profit (MP) and Average Profit (AP) from the quota harvest for the average-sized vessel. The

19 Considering 2025, it would be 30% of the fleet; for 2030, 15% of the fleet.
20 Note that model assumes current strict entry regime. Thus, the resultant fleet composition is based on the exactly the same subset of the Polish fleet, i.e. trawlers over 10 m with cod harvest permits, and presents the fleet in terms of the same vessels that would remain in the fishery under each analyzed scenario.
results suggest that the 2008 cod quota is about 5 times smaller than the quota maximizing the marginal profit. This result indicates a high potential for improved profitability under the ITQ system.

Under quota trade (ITQ scenario), the market price of quota would form by firms exchanging units of initial allocation until the unit rents for each quota equalize across firms (Squires and Kirkley 1996). The gradually forming price dictates the decision regarding whether to harvest the given allocation or sell it to another vessel. If the quota price is lower than the marginal profit (unit quota rent) associated with harvesting additional units of quota-regulated species, the vessel prefers to harvest an additional unit of quota and buys additional allowance to continue its activity in the ITQ-regulated fishery. On the other hand, if the quota price exceeds the unit quota rent, the vessel sells the initial allocation and enjoys higher profits without engaging in the cod fishery or by reducing its scale or altering its scope of operation (equation 6). The estimated optimal quota allocation in the ITQ scenario reflects the described rationality. Simulating the ITQ market for the investigated fleet and TAC, the derived quota lease price is 3.62 PLN per kg. Considering the same threshold for exit incentives as in the first scenario (12 years), presents the fleet structure under the ITQ scenario as bar filled with upward diagonal lines (ITQ scenario). Note that this includes vessels that do not use the buyback opportunity to exit the fishery, that is, vessels that continue to harvest cod, vessels that temporarily sell their initial cod allocation and utilize their capital in other available fisheries, and vessels that decided to wait for the ITQ introduction to exit and fully capitalize their quota value.

The buyback option would be attractive for 2% of the fleet (4 out of 177 vessels) when evaluating the incentives in terms of the value of the firm trading quotas immediately after the buyback. However, the fleet in question would decrease by an additional 21% (37 out of the remaining 173 vessels) right after the quota trade was introduced. The fleet reduction would occur when the vessel owners can sell their allocations permanently to other participants of the cod fishery and capitalize the value of quota instead of capitalizing the value of vessel investment. Moreover, only about 31% of the trawler fleet (55 vessels) would remain in the cod fishery. These vessels buy the additional quota, and in this way, the individual marginal profit and industry rent are both maximized. Note that, if we know the variable netput prices, individual fixed factors and the profit structure, i.e. equation 7 estimates, we can derive the optimal quantity of each variable netput by applying Hotelling’s lemma (equation 8). Consequently, manipulating quota output for individual firms when simulating trade, we simultaneously estimate the changes in harvest of other species and variable inputs. In the case of selling quota, the negative elasticity of pelagic species unregulated by individual quotas with respect to cod

\footnote{We assume no transaction and information costs in the ITQ scenario that hamper the trade.}
Fig. 3 Comparison of initial trawler fleet (2008) with expected composition under different scenarios ($t_{ex} = 12$).

The results suggest a continuation of the cod fishery by small and mid-size units, whereas large vessels would rather sell their initial allocation and concentrate on catching other species. This depicts capitalization of profit gains from tradability into the owned capital option through substitution between quota and alternative output supplies, i.e. harvest of other species. Comparing the ITQ scenario results with the ITQ scenario subset of cod quota buyers, the model predicts considerable amount of quota trade and cod fleet consolidation. Thus, we show that when anticipating ITQs, the scrapping payment is far less effective compared to the base scenario of IVQs, but the exact results are highly dependent on the underlying profit structure of the fleet. Estimated substitutability between variable and fixed outputs allows better allocation of variable inputs necessary for production given that the fixed physical capital stock remains the main restrictive factor. But the flexibility that is embedded in the trade option allows improved profitability (through relaxation of the local Le Chatelier effect) and, as a consequence, the attractiveness of the buyback automatically decreases.

We proceed by comparing the fleet structure derived with the model for the two described scenarios, BAU and ITQ, with the fleet structure observed.

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22 We verified that optimal harvest derived in ITQ scenario does not imply unrealistic effort. This is done by calculating a sum of input demand equations outputs, i.e. time at sea using demersal and pelagic gear, following equation 8.
after the buyback has ended. Then, we conduct a sensitivity analysis with respect to parameter $t_{ex}$, the expected time of vessel exploitation, and the ITQ introduction time frame. This part of the discussion, supported by figure 5, depicts fleet dynamics as a function of the uncertain parameters. If we consider that vessels are expected to remain active for up to 12 years, the expected number of vessels that would remain under IVQs is 65 out of the original 177. With the same expected capital durability, if ITQs were expected soon after the buyback ends, considerably more vessels (173 vessels) are predicted to stay active. These two values bracket the number of observed vessels in 2012 (118 vessels), the year after the buyback program finished. Considering a longer vessel exploitation time frame, the anticipation of the introduction of ITQs could be further moved towards the future. But even a NPV for 20 years of vessel use indicates a larger fleet than under the BAU scenario. Therefore, the results provide empirical evidence that there was some expectation that quota tradability would be introduced at some date following the buyback. As shown in figure 5, the only situation that would not support our results is a very short expected capital use time frame, which is extremely unlikely when considering a well-established industry.

The final decisions also depend upon additional factors with potential for future research. These include future TAC dependence on stock recovery or substantial recruitment driven by changes in environmental conditions (Grainger and Costello 2014), as has arisen before in the Baltic Sea, as well as

Fig. 4 Comparison of MP and AP for average vessel size (at average 2008 prices).

Fig. 5 Fleet dynamics as a function of expected time of vessel exploitation and anticipated time to the introduction of ITQs.
whether the quota is based on current allocations. Alternative quota redistribution schemes can impact the results (Libecap and Anderson 2009). These include future quota based on alternative vessel parameters, historical catch or other rules, or redistribution through auction. The disinvestment decision also highly depends upon available strategies for the transition period, including harvest of secondary target species, and therefore on associated regulations.

5 Concluding remarks

The firm’s expectations over an anticipated policy change and potential tradability of individual quotas, and whether expectations are myopic or rational, impact the incentives for a fishing vessel owner’s decision to exit the fleet. The individual quota that can be soon sold presents a valuable asset that is potentially of sufficient value to continue business as usual, rather than exit the fleet in the buyback, in return for the expected higher future profits resulting from trade.

In the empirical application to the Polish trawler fleet, several factors proved essential to explain the post-buyback fleet structure: the potential ability to exit through the buyback and size of compensation payment; the expected transition from a non-transferable to transferable individual quota program, its timing, and resulting rational expectations over gains from trade; the potential to otherwise restructure the production process through changes in multispecies caught and input substitution; and relaxation of the local Le Chatelier effect. Notably, if the firm expects quota trade, its perceived future profitability is higher and the same compensation payments attract considerably fewer units. Results indicate that the anticipation of transferability delayed the exit of the vessels willing to wait through the transition period. The number of vessels observed in 2012, which brackets the two analyzed scenarios, indicates that to some degree, firms expected the ITQs in the future. Thus, the uncertainty induced by the government over the introduction of tradable quotas considerably impacted the fleet restructuring process. Such a situation, however, may not necessarily be adverse from the society’s standpoint as, in turn, it implies a lower cost to taxpayers.

Several other results emerge. Quota trade can be capitalized not only into quota value, but also capitalized through substitution between regulated and unregulated species. Consequently, expected ITQs alter the expected NPV upon which vessel owners act, and the response to the buyback, is potentially shifted. This spillover effect is particularly important information for managers due to the impacts on other harvestable stocks. In this way, the study motivates a broader view of marine governance that simultaneously regulates multiple species in conjunction with other impacts such as consequences for
local economies.\textsuperscript{23} This paper highlights the potential broad repercussions of merely speculating on future regulations.

In conclusion, the asymmetries in vessel profit structure create a potential opportunity for regulators aiming for optimal physical capital capacity to substantially increase rents through arbitrage efficiency, relaxation of local Le Chatelier effects, and allowing vessel production restructuring, including industry exit, following quota trade.

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\textsuperscript{23} Although the analysis was conducted within a partial equilibrium framework, use of shadow prices often accounts for secondary impacts.
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Appendix A  Separability

Homothetic separability between all inputs and all outputs in the short run, conditional upon fixed netputs, implies a transformation of the form:

\[ f(X_{\text{out}}; Z_{\text{out}}) - g(X_{\text{in}}; Z_{\text{in}}) = 0, \]  

(A.1)

where \( f(\cdot) \) and \( g(\cdot) \) are linearly homogeneous aggregator functions that provide a consistent composite output and input indices respectively. Input-output separability implies no specific interactions between outputs, whether quota-regulated or variable, and inputs, whether variable or quasi-fixed, implying that it is possible to specify one composite output and one composite input. This is of particular interest in the case of fisheries, where it is common to aggregate harvest to a composite output or use total effort as a composite input. Homothetic input-output separability implies that the composition of variable and quota-regulated outputs within a restricted profit function framework is independent of input prices and fixed inputs, and the relationship between the quota-regulated and unregulated species depends upon the functional form of the linearly homogeneous aggregator function for the composite output. This condition can be written as: (1) \( \partial \left( \frac{\partial (P, W, Z)}{\partial p_i} \right) / \partial p_i' = 0 \) for every \( i, i' \in I_{\text{out}} \) and \( i'' \in I_{\text{in}}, \) (2) \( \partial \left( \frac{Z(P, W, Z)}{\partial p_i} \right) / \partial p_i' = 0 \) for every \( i \in I_{\text{out}}, j \in J_{\text{out}} \) and \( i' \in I_{\text{in}}, \) (3) \( \partial \left( \frac{\partial (P, W, Z)}{\partial z_j} \right) / \partial z_j = 0; i \neq i' \) for every \( i, i' \in I_{\text{out}} \) and \( j \in J_{\text{in}} \) and (4) \( \partial \left( \frac{\partial (P, W, Z)}{\partial z_j} \right) / \partial z_j' = 0; \) for every \( i \in I_{\text{out}} \), \( j \in J_{\text{out}} \) and \( j' \in J_{\text{in}} \).

Appendix B  Non-jointness

Input or output non-jointness implies that there are no benefits from combining the production of outputs or using combinations of inputs; the costs of producing outputs or using inputs individually are the same. In this case, the production process can be decomposed into a series of independent processes and the multiproduct or multiinput technology can be expressed as a sum of individual restricted profit functions. In the case of fisheries, a single output profit function implies a separate harvest of each species and there are no economies or diseconomies of scope, whereas a single-input profit function implies the sequential use of different inputs. The extension of non-jointness of particular interest in this context is almost non-jointness (Livernos and Ryan 1989), in which the production process can be separated into independent processes that depend on the same vector of shared inputs (called public). In this context, elements of \( Z \) may be a factor of production that is endogenously selected by the firm in the long run (e.g., the vessel and its equipment in the case of fisheries), a factor of production that is supplied by the government with the properties of a public good or it may incorporate externalities such as crowding in fisheries. In this context, fixed inputs \( (Z_{\text{in}}) \) are taken as elements of the shared inputs vector and the non-joint in inputs total profit function can be written as:

\[ H(P, W; Z) = \sum_{i \in I_{\text{out}}} \pi^r(i)(p_i, P_{\text{in}}; Z_{\text{in}}) + \sum_{j \in J_{\text{out}}} (w_j z_j + \pi^r(j)(p_{\text{in}}; Z_{\text{in}})) + \sum_{f \in J_{\text{in}}} w_f z_f. \]  

(B.1)

Here, \( \pi^r(i)(p_i, P_{\text{in}}; Z_{\text{in}}), i \in I_{\text{out}}, \) is a single-output restricted profit function, \( w_j z_j + \pi^r(j)(p_{\text{in}}; Z_{\text{in}}), j \in J_{\text{out}}, \) is a restricted profit from harvesting restricted output that consist of revenue and restricted profit function indicating the cost of quota harvest. The last expression \( \sum_{f \in J_{\text{in}}} w_f z_f \) is the cost of fixed inputs added for completeness. \( P_{\text{in}} \) indicates the vector of variable input prices and \( P_{\text{out}} \) the vector of unrestricted output prices. The requirement for non-jointness in inputs is: \( \partial^2 H(P, W; Z)/\partial p_i p_i' = 0; i \neq i' \) for all \( i, i' \in I_{\text{out}} \).
and $\partial^2 J(P, W; Z)/\partial p_i z_j = 0$ for all $i \in I_{out}$ and $j \in J_{out}$. Accepting non-jointness in inputs implies that harvest activities associated with any species, both unrestricted and restricted, are independent with the exception of sharing the fixed inputs. The total non-joint in outputs profit function is specified as:

$$J(P, W; Z) = \sum_{i \in I_n} \pi^{\tau(i)}(p_i, P_{out}; Z) + \sum_{j \in J} w_j z_j.$$  (B.2)

Here $\pi^{\tau(i)}(p_i, P_{out}; Z), i \in I_n,$ is a single-input restricted profit function. The requirement for non-jointness in outputs is: $\partial^2 J(P, W; Z)/\partial p_ip_{i'} = 0; i \neq i' \text{ for all } i, i' \in I_{in}$. In the case of non-jointness in outputs, there are multiple production functions for each type of variable input, for which the optimal choice depends on fixed factors.

**Appendix C  Estimation procedure details**

The model is estimated using a modified `micEconSNQP` package for R software (Henningsen 2014). The modifications include adding third order terms for non-linear marginal relationships and rewriting the function for the variance-covariance matrix using the wild bootstrap method. The initial run violates the convexity in prices requirement, but convexity can still be imposed, and the model continues to identify elasticities between pairs of netputs. Koebel et al (2003) describe the procedure. The procedure implies a correction of uncorrected residual bootstrap proposed by Davidson and MacKinnon (2007). The transformed actual residual for each observation, transform it, and multiply it by an IID drawing from a distribution with expectation 0 and variance 1 (Davidson 2007). Here, we use wild efficient residual bootstrap by Davidson and MacKinnon (2007). The transformed residual is derived as: $u_i^* = \sqrt{(N/(N-K))} u_i$, where $u_i$ is original residual, $N$ is number of observations, $K$ is number of coefficients, and $v_i$ is a random variable from Rademacher distribution, according to which: $v_i = \begin{cases} 1 & \text{with probability 0.5} \\ -1 & \text{with probability 0.5} \end{cases}$. The data generation process takes the form: $x_{it}^* = \bar{e}_{it} + u_{it}^*$, where $\bar{e}_{it}$ is the predicted value for netput $i$ from the original input demand or output supply equation, and $u_{it}^*$ is the residual bootstrap. In case of simultaneous equations model, all residuals for a given observation are multiplied by the same value of $v_i$ to preserve the correlation between disturbances (Davidson and MacKinnon 2007).

The p-values calculated for a one-tailed test indicating probability of rejecting the value of opposite sign or zero follow: p-value=$\begin{cases} \frac{1}{R} \sum_{r=1}^{R} I(\alpha_r \leq 0) & \text{for } \hat{\alpha} > 0 \\ \frac{1}{R} \sum_{r=1}^{R} I(\alpha_r \geq 0) & \text{for } \hat{\alpha} > 0 \end{cases}$, where $r$ is bootstrap sample, $R$ is sum of bootstrap samples calculated, here 999, $\alpha_r$ is coefficient value for
\( r \)-th bootstrap sample estimated with the same methods as the original model and \( \hat{\alpha} \) is the original estimate. Consequently, the p-values are based on the empirical distribution and there is no need to make any assumption about the population’s distribution.