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Abstract. A framework is developed to measure the welfare effects of individual quota reforms in multiproduct industries using the multimarket welfare measure techniques suggested by Just, Hueth, and Schmitz (1982) and the concept of virtual price in the production theory literature (Neary 1995; Squires and Kirkley 1996). Under joint in input production it is shown that quasi-rent under a single quota can be measured by the producer surplus either in the output market for quota output or in the quota market. Under multiple quotas the welfare effects of quota policies can be measured in one of the quota markets using inverse derived equilibrium demand curves. These results are obtained for a joint in input technology, where positive production of at least one of the quota outputs is necessary for the firm to continue to operate. Application of the inverse derived demand functions for welfare measurement is shown for both transferable and non-transferable quotas.

Mesures des effets de bien-être dans des industries à plusieurs produits: le cas des pêches où il y a plusieurs espèces et des quotas individuels. Le mémoire développe un cadre d’analyse pour mesurer les effets de bien-être des réformes de quotas individuels dans des industries à plusieurs produits en utilisant les techniques de mesure de bien-être dans un monde à plusieurs marchés suggérées par Just, Hueth, et Schmitz (1982) et le concept de prix virtuel dans la littérature sur la théorie de la production (Neary 1995; Squires et Kirkley 1996). Quant la technologie de production implique des intrants conjoints, on montre que la quasi-rente dans le cas d’un seul quota peut être mesurée par le surplus du producteur soit dans le marché du produit pour le volume de produit contingenté soit dans le marché contingenté. Quand il y a de multiples quotas, les effets des politiques de contingentement peuvent être mesurés dans l’un des marchés contingentés en utilisant les courbes de demande inverses dérivées d’équilibre. Ces résultats sont obtenus pour une technologie de production qui implique des intrants conjoints quand la production positive d’au moins l’un des produits contingentés est nécessaire pour que l’entreprise continue à opérer. On applique les fonctions de demande inverses dérivées à la fois aux quotas transférables et non-transférables.

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1. Introduction

Traditional welfare effects of output controls in fisheries are analysed using profit functions\(^1\) (Grafton 1995) or optimization techniques\(^2\) (Danielsson et al. 1997). In several studies of multispecies fisheries, the production technology is restricted to be either non-joint\(^3\) or with fixed proportions, which simplifies the measurement of welfare effects (see, e.g., Geen and Nayar 1989; Clark 1990; Arnason 1993; Eide and Flaaten 1993). The technology can then be described by separate production functions. In the case of joint in input technology, the analysis of welfare effects is more difficult, because changes in output levels have spillover effects to other outputs.

In this paper an analysis of welfare measures of individual quota reforms in multiproduct industries is provided, using multispecies fisheries as reference. The purpose of the paper is to set up a framework to measure changes in producer surplus, using the multimarket welfare measure techniques suggested by Just, Heuth, and Schmitz (1982). By combining the virtual price framework in the production theory literature (Neary 1985; Fulginiti and Perrin 1993; Squires 1994) with welfare measure techniques, the paper makes two contributions. First, for a multiproduct firm with a joint in input technology, it is shown that the area under an inverse derived demand curve for quota corresponds to the producer surplus measured in the output market and equals the quasi-rent.\(^4\) The inverse derived demand curve provides a more suitable welfare measure, since the quantity is given as exogenous and the price is endogenous. Secondly, in the literature (Squires and Kirkley 1995, 1996), the industry rent of two individual transferable quotas (ITQs) in multispecies fisheries with a joint in input technology has been measured by the sum of the producer surplus in the quota markets using equilibrium inverse derived demand curves. It is shown that it is sufficient to compute the area bounded by the inverse derived demand curve for the quota species in the one quota case, if the quota species is a necessary output. In the two- or multi-quota case it is shown that the change in profit following implementation of the last quota can be measured by the area bounded by the equilibrium inverse derived demand curve for the last the quota species, that is, in one of the quota markets. All that is needed in an empirical analysis is the equilibrium inverse derived demand functions for quota of the relevant species, that is, it is not necessary to estimate all the profit functions.

The outline of the paper is as follows. The model and the basic concepts are presented in section 2. In section 3 the welfare effects of Individual Non-Transferable Quotas (INTQs) are shown, while ITQs are dealt with in section 4. In section 5 the results of the paper are discussed; finally, in section 6 some conclusions are drawn.

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1 In the single quota case exceptions are Lanforsieck and Squires (1992) and Squires, Alauddin, and Kirkley (1994) which use the inverse derived demand function for quota.
2 Here a production relationship is specified and an objective function is maximized, for example, profit.
3 As noted by Kirkley and Strand (1988), non-jointness is a common assumption in bio-economic models of multispecies fisheries.
4 In the single-output case, Rucker, Thurman, and Summer (1995) have used the inverse derived demand curve for quota for an analysis of the welfare effects of tobacco quotas.
2. The model

There is one industry, the fishing industry, with multiproduct firms. The industry is assumed to face perfectly elastic demand for its outputs and the supply curves for the variable inputs are assumed perfectly price elastic.

The short-run (called the restricted) profit function for the firms can be defined as follows:

\[ \Pi(p, w; K) = \sum_{i=1}^{n} p_i y_i(p, w; K) - \sum_{j=1}^{m} w_j x_j(p, w; K), \]

where \( p_i \) is output price of species \( i \), \( w_j \) is price of input factor \( j \), and \( K \) represents the fixed capital stock. When a variable or parameter is without subscript, it can be interpreted as a vector. The profit-maximizing levels of outputs and variable inputs are given by \( y_i(p, w; k) \), \( i = 1, \ldots, n \) and \( x_j(p, w; k) \), \( j = 1, \ldots, m \). This profit function measures the quasi-rent, which is the variable profit. Quasi-rent is a rent to the fixed factors, but it may not persist in the long run, as, for example, factor rent. Quasi-rent is more useful as a measure of the producer welfare than profit (Just, Hueth, and Schmitz 1982).

The model is a short-run model. Besides being conditional on the existing and fixed capital, the model is also conditional on the existing and available biomass. Changes in management, for example, implementation of individual quotas, can have an important impact on investment\(^5\) in the industry. Changes in biomass\(^6\) influence the productivity of the industry and can have an effect on the optimal choice of production. By Hotellings lemma,

\[ \frac{\partial \Pi}{\partial p_i} = y_i(p, w; K) \]  \hspace{1cm} (2)
\[ \frac{\partial \Pi}{\partial w_j} = x_j(p, w; K). \]  \hspace{1cm} (3)

These supply and demand functions include optimal adjustment in other outputs and inputs besides adjustment in the considered output or input as some of the exogenous variables, that is, output and input prices, change.

2.1. Measuring producer welfare

The production technology will assume joint in input production with the technology interdependence that not all output compositions are possible. More precisely, it is assumed that there is at least one output for which zero production is only possible, if and only if no production takes place at all; that is, all the output

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5 If the capital is considered as sunk, however, the short-run measure of quasi-rent can also be interpreted as long-run rent. See Squires and KIRKLEY (1995) for a discussion.

6 Increase in biomass may reduce unit cost of harvesting and hence increase the productivity of the industry.
levels are zero.\footnote{Turner (1997) analyses a situation where there is imperfect control over the output composition, defined as a situation where all outputs are necessary. Hence, the assumption here is less restrictive.} This output can be called a necessary output, because positive production levels of this output are required for the firm to continue to operate (Just, Heuth, and Schmitz 1982). Multispecies fisheries are an example of fisheries where outputs are necessary. In nearly all empirical work on production technologies in multispecies fisheries, joint production with limited ability to adjust the output composition has been confirmed (see, e.g., Kirkley and Strand 1988; Squires 1987; Squires and Kirkley 1991, 1996; Campbell and Nicholl 1994).

The producer surplus is a geometric concept and is defined as the area above the supply curve and below the price line of the corresponding firm. Following Just, Heuth, and Schmitz (1982), output 1 is defined as a necessary output, where $\Pi(y_1 = 0) = 0$. Define $p_1^0$ as the maximal price of output 1, where production just ceases and the firm shuts down; that is, $\Pi(p_1^0, P_h, w; k) = 0$. $P_h$ is an $n - 1$ vector of prices of the other outputs except output 1.

The producer surplus, $\text{ps}_1$, can now be calculated in output market for $y_1$ with prices $(p, w)$:

\[
\text{ps}_1 = \int_{p_1^0}^{p_1} y_1(p, w; K) dp_1 = \int_{p_1^0}^{p_1} \frac{d\Pi}{dp_1} dp_1 
= \Pi(p, w; K) - \Pi(p_1^0, P_h, w; K) = \Pi(p, w; K).
\]

Thus, the total quasi-rent can be measured in one output market by the producer surplus in this market, if the output is a necessary output. This result can be generalized to any output (input) market, for which the output (input) is necessary for the firm (see Just, Heuth, and Schmitz 1982). Equation (4) applies to cases where at least one of the outputs is a necessary output.

This also implies that changes in any prices or multiple price changes can be measured in one market.\footnote{If the output is not a necessary output, it is still possible to measure the changes in quasi-rent due to a price change of the output in the associated output market. Even if the price change shifts other output supplies, the change in quasi-rent can be completely measured in the associated output market.} Changes in quasi-rent following multiple price changes are measured as changes in producer surplus in the market for the necessary output; that is, the producer surplus at the final prices minus the producer surplus at the initial prices. In the case of multiple price changes, the overall change in quasi-rent can also be measured by successively calculating the change in producer surplus over all markets in which prices change\footnote{When the changes in producer surplus in each market are calculated, the price change for the associated market is conditional on all changes previously considered; that is, a given price path is chosen. Because of path independence (see Just, Hueth, and Schmitz 1982), the order of price changes is arbitrary and any price path can be chosen.} and then simply summing these changes in the producer surplus to get the total change in quasi-rent.
3. Welfare measures of quota policies

Impose an exogenous given quota on, for example, output 1:

\[ y_1 \leq q_1. \]  

The quota allocation gives each firm the right to produce a given amount within a specific period. The quota cannot be traded. In fisheries management such quotas are called Individual Non-Transferable Quotas (INTQs).\(^{10}\)

Solving the problem gives the following supply and demand functions (see Fulginiti and Perrin, 1993; Squires 1994):

\[
y_i^{\text{INTQ}}(p, w, q_1, K) = y_i(p_1 - \lambda_1, p_h, w; K), i \geq 2
\]

\[
x_j^{\text{INTQ}}(p, w, q_1, K) = x_j(p_1 - \lambda_1, p_h, w; K),
\]

where \( \lambda_1 \) is the shadow price of the quota constraint. If the price of output 1 is \( p_1 - \lambda_1 \) in the unconstrained case, the supply and demand functions in the INTQ case are equal to the supply and demand functions in the unconstrained case at prices \( p \) and \( w \). The price \( p_1 - \lambda_1 \) is called the virtual price and expresses the firm’s marginal valuation of output 1 (see Rothbarth 1941; Neary and Roberts 1980). The virtual price is defined as the price where the firm exactly and freely supplies the quota level. The optimal quasi-rent for a fixed \( K \) can be written as:

\[
\Pi^{\text{INTQ}}(p, w; q_1; K) = \sum_{i=2}^{n} p_i y_i^{\text{INTQ}} - \sum_{j=1}^{m} w_j x_j^{\text{INTQ}} + p_1 q_1
\]

\[
= \sum_{i=2}^{n} p_i y_i + (p_1 - \lambda_1) y_1 - \sum_{j=1}^{m} w_j x_j + \lambda_1 q_1
\]

\[
= \Pi(p_1 - \lambda_1, p_h, w; K) + \lambda_1 q_1.
\]

Equation (8) is the constrained variable profit function (Neary 1985; Fulginiti and Perrin 1993; Squires 1994). Application of Hotelling’s lemma gives the supply and demand functions (6) and (7). Differentiating (8) with respect to the quota gives (see Fulginiti and Perrin 1993; Vestergaard 1996):

\[
\frac{\partial \Pi^{\text{INTQ}}}{\partial q_1} = \lambda_1(p, w; q_1, K).
\]

10 INTQs are more than production quotas. The duration of the allocation is normally long – quotas are assigned for more than one period – but the actual quota-level will normally change from period to period depending on the overall resource situation. In many cases the quotas are tied to a given vessel and follow the vessel in a trade. Hence, the INTQs form a type of quasi-property right, a right to produce of uncertain duration without transferability.
This is the inverse derived quota demand function and it is a function of output and input prices and the quota. The firms adjust the endogenous implicit marginal valuation of quota, that is, $\lambda_1$, subject to the exogenous given quota, $q_1$ (Squires 1995). In what follows it will be shown that the quasi-rent of the firm producing subject to a single output quota can be measured by the producer surplus both in the output market for the quota species, or in the implicit quota market for the quota species, by the area behind the inverse derived quota demand curve (assuming the quota species is a necessary output).

Figure 1 gives the area $a + b$ which is the producer surplus in the output market of the quota species. The supply curve is equation (2) up to the quota level, the unconstrained supply function of output $y_1$. The producer surplus is

$$
PS^{INTQ}_1 = \int_{p_1^0}^{p_1 - \lambda_1} y_1(p, w; K) dp_1 + \int_{p_1 - \lambda_1}^{p_1} q_1 dp_1
$$

$$
= \int_{p_1^0}^{p_1 - \lambda_1} \frac{\partial \Pi}{\partial p_1} dp_1 + \int_{p_1 - \lambda_1}^{p_1} q_1 dp_1
$$

$$
= \Pi(p_1 - \lambda_1, p_h, w; K) + \lambda_1 q_1
$$

$$
= \Pi^{INTQ}(p, w; q_1, K),
$$

where equation (8) has been used. Area $a$ is found by the first integral, the usual price-based measure, and area $b$ by the second integral in equation (10). Area $a$ may by called the harvest surplus and area $b$ the quota surplus, following Rucker, Thurman, and Summer (1995).

The area under the implicit derived quota demand curve up to the quota-level $q_1$, that is, the sum of area $c + d$, also measures the quasi-rent (see figure 2):
Area \( c + d = \int_0^{q_1} \lambda_1(p, w; q_1, K) dy_1 \)

\[ = \int_0^{q_1} \frac{\partial \Pi^{\text{INTQ}}}{\partial y_1} dy_1 \]

\[ = \Pi^{\text{INTQ}}(p, w; q_1, K), \]

using (9) and the assumption that \( y_1 \) is a necessary output; that is, \( \Pi(y_1 = 0) = 0 \). Since the sum of these areas \( c + d \) is equal to the producer surplus in the output market of the quota species, the area can also be called producer surplus. Areas \( c \) and \( d \) correspond to areas \( a \) and \( b \) in figure 1, respectively.

The inverse derived quota demand function captures the optimal adjustment in input use and other outputs as the quota change, and it reflects the firm’s implicit marginal evaluation of the quota species as the quota level varies. Since the quasi-rent can be measured by the producer surplus associated with the implicitly inverse derived demand curve, evaluation of changes in quota levels can be considered in the implicit quota market. Using the inverse derived demand curve when measuring welfare changes of quota policies (quantity) offers an approach that has more intuitive appeal than the traditional measure using the supply curve and changes in prices. Also, changes in quota levels can be measured directly using the inverse derived demand curves, while using the output market focusing on changes in prices (as a result of the change in quota-level) will provide only the change in harvester surplus and requires adding changes in the quota surplus.

We will now show that the welfare effects of several quotas can be measured in one of the implicit quota markets. Imposing an additional quota on species 2:

\[ y_2 \leq q_2. \]
Solving gives the following implicit inverse demand functions for quotas (see Vestergaard 1996):

\[ \lambda_1 = \lambda_1(p, w; q_1, q_2, K) \]  \hspace{1cm} (13)

\[ \lambda_2 = \lambda_2(p, w; q_1, q_2, K). \]  \hspace{1cm} (14)

The endogenous shadow price of each quota species is a function of the exogenous quota level of all the quota species. The difference between these demand functions and traditional demand functions is that traditional demand functions are conditional on input and output prices and the (implicit) quota price of the other quota species, while the demand functions (13) and (14) describe the total response, including the spillover effects from the other quota market, and are conditional on input and output prices and the quota level of the other quota species. These demand curves are called equilibrium demand curves (Just, Hueth, and Schmitz 1982). The constrained variable profit function is

\[ \Pi^{\text{INTQ}(p, w; q_1, q_2, k)} = \sum_{i=3}^{n} p_i \tilde{y}_i \tilde{\lambda}_q - \sum_{j=1}^{m} w_j \chi_j \tilde{\lambda}_q + p_1 q_1 + p_2 q_2 \]

\[ = \sum_{i=3}^{n} p_i y_i + (p_1 - \lambda_1) q_1 + (p_2 - \lambda_2) q_2 \]

\[ - \sum_{j=1}^{m} w_j \chi_j + \lambda_1 q_1 + \lambda_2 q_2 \]

\[ = \Pi(p_1 - \lambda_1, p_2 - \lambda_2, p_k, w_j, K) + \lambda_1 q_1 + \lambda_2 q_2. \]  \hspace{1cm} (15)

Differentiating (15) with respect to the quota \( q_1 \) gives (see Vestergaard 1996):

\[ \frac{\partial \Pi^{\text{INTQ}}}{\partial q_1} = \lambda_1(p, w; q_1, q_2, K). \]  \hspace{1cm} (16)

The welfare effect of a marginal change in quota level is given by the implicit quota price. The producer surplus in the implicit quota market for output 1 is then

\[ ps_1^{\text{INTQ}} = \int_0^{q_1} \lambda_1(p, w; y_1, y_2, K) dy_1 = \int_0^{q_1} \frac{\partial \Pi^{\text{INTQ}}}{\partial y_1} dy_1 \]

\[ = \Pi^{\text{INTQ}(p, w; q_1, q_2, K)}. \]  \hspace{1cm} (17)

The quasi-rent can be measured by the area under the inverse derived demand curve for one of the quota species if the quota species is a necessary output. The quasi-rent obtained under the quota politics, that is, (11) or (17), can be compared with the quasi-rent prior to the quotas. Welfare analysis of changes in quota politics of one species can in this case be conducted solely in the (implicit) quota market of
the species. Changes in several quotas simultaneously can also be conducted in one market in two steps. The first step is to calculate the producer surplus as the size of the area under the inverse derived demand curve given the new quota levels and the old quota levels, respectively. The change in producer surplus and quasi-rent is then found to be the difference between the size of the areas. This is a different result from the standard result in the literature, where the welfare effects of changes of two or more distortions have to be analysed in all the distorted markets. Under quotas and with one necessary output, the welfare analysis of quota policies can be conducted in one and only one market.\textsuperscript{11} The situation where the quotas are transferable is now considered.

4. Individual transferable quotas (ITQ\textsubscript{s})

Under ITQ\textsubscript{s}\textsuperscript{12} firms adjust their quota-holdings \( q \) given an exogenous equilibrium quota price \( \lambda_{1}^{\text{ITQ}} \), which is simultaneously generated and determined in the quota market. The multiproduct firm \( k \)'s constrained variable profit function under ITQ on one output is given by

\[
\Pi_{k}^{\text{ITQ}}(p, w, \lambda_{1}^{\text{ITQ}}, w_{1k}; K) = \sum_{i=2}^{n} p_{i} y_{ik}^{\text{ITQ}} - \sum_{j=1}^{m} w_{j} x_{jk}^{\text{ITQ}} + p_{1} q_{1k} - \lambda_{1}^{\text{ITQ}}(q_{1k} - w_{1k})
\]

\[
= \sum_{i=2}^{n} p_{i} y_{ik}^{\text{ITQ}} + (p_{1} - \lambda_{1}^{\text{ITQ}}) y_{1k}^{\text{ITQ}} - \sum_{j=1}^{m} w_{j} x_{jk}^{\text{ITQ}}
\]

\[
+ \lambda_{1}^{\text{ITQ}} q_{1k} - \lambda_{1}^{\text{ITQ}}(q_{1k} - w_{1k})
\]

\[
= \Pi_{k}(p_{1} - \lambda_{1}^{\text{ITQ}}, p_{h}, w; K) + \lambda_{1}^{\text{ITQ}} q_{1k} - \lambda_{1}^{\text{ITQ}}(q_{1k} - w_{1k}),
\]

where \( q_{1k}(p, w, \lambda_{1}^{\text{ITQ}}, K) \) is firm \( k \)'s derived demand for quota of output 1. Note that the initial distribution of quota \( w_{1k} \) does not influence the firm's choice of quota,\textsuperscript{13} \( q_{1k} \), but has an impact on the distribution of profit.\textsuperscript{14}

Horizontal summation of the firm's derived demand functions for quota gives the industry demand curve. The supply of quota of species 1 is fixed and exogenous given by a Total Allowable Catch (TAC\textsubscript{1}). By equalizing the demand and supply,

\textsuperscript{11} Just, Hueth, and Schmith (1982) found that the welfare effects of implementation of another quota could be assessed in the market for the newly imposed quota. Here, we claim that even welfare effects of changes in the quotas already implemented can be analysed in one of the quota markets.

\textsuperscript{12} For a general overview of ITQ see Grafton, Squires, and Kirkley (1996). For an overview of ITQs in multispecies fisheries, see Squires et al. (1998).

\textsuperscript{13} As noted by one of the referees, however, if, for instance, there is transaction cost, the initial distribution of quota may influence the demand of quota.

\textsuperscript{14} See also Montgomery (1972). Here it is assumed that the initial distribution of individual quotas is free. An auction price or rental price equal to \( \lambda_{1}^{\text{ITQ}} \) does not change the analysis of the welfare effects; however, the distribution of the welfare effect will differ.
the equilibrium quota price, $\lambda_1^{\text{TO}}$, can be found as a function of output and input prices and the exogenous given TAC_1:

$$\sum_k q_{1k}(p, w, \lambda_1^{\text{TO}}, K) = \text{TAC}_1$$

$$\Rightarrow$$

$$\lambda_1^{\text{TO}} = \lambda_1^{\text{TO}}(p, w; \text{TAC}_1, K).$$

This function is the inverse derived market demand function for quota. Define $\Pi^{\text{TO}}$ as the industry constrained variable profit function:

$$\Pi^{\text{TO}} = \sum_k \Pi_k^{\text{TO}}$$

$$= \sum_k \left( \sum_{i=2}^n p_i y_{ik}^{\text{TO}} - \sum_{j=1}^m w_j x_{jk}^{\text{TO}} + p_1 q_{1k} - \lambda_1^{\text{TO}}(q_{1k} - w_{1k}) \right)$$

$$= \sum_{i=2}^n p_i y_{i}^{\text{TO}} - \sum_{j=1}^m w_j x_{j}^{\text{TO}} + p_1 \text{TAC}_1$$

$$= \Pi^{\text{TO}}(p, w; \text{TAC}_1, K).$$

where it has been used that $\Sigma_k q_{1k} = \Sigma_k w_{1k} = \text{TAC}_1$.

Differentiating (20) with respect to $\text{TAC}_1$ gives, using equation (18) (see Vestergaard, 1996):

$$\frac{\partial \Pi^{\text{TO}}}{\partial \text{TAC}_1} = \lambda_1^{\text{TO}}.$$  

(21)

The area under the inverse derived market demand curve for quota of species 1 is the industry producer surplus under rTQ and it measures the industry quasi-rent.$^{15}$

$$\Psi_1^{\text{TO}} = \int_0^{\text{TAC}_1} \lambda_1^{\text{TO}}(p, w; Q_1, K) dQ_1$$

$$= \int_0^{\text{TAC}_1} \frac{\partial \Pi^{\text{TO}}}{\partial Q_1} dQ_1$$

$$= \Pi^{\text{TO}}(p, w; \text{TAC}_1, K).$$

(22)

Welfare effects of changes of quota-levels can be conducted in the quota-market using a quantity-based measure, the inverse derived market demand for quota.

$^{15}$ Remember the assumption that output 1 is a necessary output.
It is easy to extend the analysis to multioutput r,nQs. An nQ on output two gives the following firm level derived demand functions for quotas.\(^{16}\)

\[
q_{1k} = q_{1k}(p, w, \lambda_1^{nQ}, \lambda_2^{nQ}; K)
\]

\[
q_{2k} = q_{2k}(p, w, \lambda_1^{nQ}, \lambda_2^{nQ}; K).
\]

(23)

(24)

By simultaneously solving the equilibrium conditions, industry supply of quotas equal to industry demand for species 1 and 2, the quota equilibrium prices can be found as

\[
\lambda_1^{nQ} = \lambda_1^{nQ}(p, w; TAC_1, TAC_2, K)
\]

(25)

\[
\lambda_2^{nQ} = \lambda_2^{nQ}(p, w; TAC_1, TAC_2, K).
\]

(26)

Equations (25) and (26) are the equilibrium inverse derived demand curves for quotas. On the industry level the endogenous quota prices adjust to the exogenous given TACs. Producer surplus in the quota market for species 1 is

\[
ps^{nQ}_1 = \int_{0}^{TAC_1} \lambda_1^{nQ}(p, w; Q_1, TAC_2, K) dQ_1
\]

\[
= \int_{0}^{TAC_1} \frac{\partial \Pi^{nQ}}{\partial Q_1} dQ_1 = \Pi^{nQ}(p, w; TAC_1, TAC_2, K).
\]

(27)

As under n,nQs, the quasi-rent can be measured by the area under the inverse derived demand curve for one of the quota-species, but under nQs, it is the inverse derived market demand curve.

One of the implications of these results is that the changes in quasi-rent following multispecies r,nQs can be measured in one quota market and welfare effects of changes in quota levels can be assessed in one quota market. To be able to do this, knowledge of the inverse derived market demand function over the whole range of quota levels is necessary. Estimation of the inverse derived market demand function, for example, equation (25), requires information on output and input prices, the TAC level of each quota species and the quota price. An alternative method of measuring the welfare effect of changes in multiple quota levels is to change one quota at a time and measure the change in producer surplus. At each step the change in quota is conditional on the already changed quota levels.

The welfare effects of allowing trade of multiple quotas can be assessed using just one quota market. For each firm the quasi-rent under non-transferable quotas and under transferable quotas\(^{17}\) can be found, as shown above, in one market using the equilibrium derived demand function. The gain of trade is simply the difference

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\(^{16}\) Since the deviation simply follows the former deviations, they are not shown here.

\(^{17}\) Under ITQ the industry quasi-rent can also be found in one quota market using the equilibrium inversely derived demand function.
in quasi-rent. Since allowing trade corresponds to removing the distortions on the firm level, it is possible to assess the welfare effects of trade from the opposite directions: imposing a non-tradable quota keeping all other quotas transferable and then assessing the change in quasi-rent for this quota market. Then continue with the next quota (the path does not matter), keeping the first quota non-transferable. Kirkley and Squires (1995, 1996) calculate the effects of trade using the first approach, but they do not recognize the equilibrium element of the inverse derived demand functions. This results in a kind of double counting of the gain of trade and misinterpretation of the multiple quotas contra single quotas, which we will look at now.

5. Discussion

From comparing the results under single quota with the results under two (or multiple) quotas, the Le Chatelier principle prevails (Squires and Kirkley 1996).\textsuperscript{18} Adjustment to changes in market/resource conditions is more limited in the two-quota case than in the one-quota case (compare equations (22) and (28)). This implies that quasi-rent from multispecies \textit{rqs} is less than quasi-rent from \textit{rqq} on a single species.

The difference between ordinary and equilibrium demand curves can be illustrated using figure 3. The assumption is that two quotas are in force. At the quota market for output 2, $D^*_2$ shows the inverse demand curve after quota of output 2, given the quota level of output 1.\textsuperscript{19} The area behind $D^*_2$ measures the entire producer surplus/quasi-rent given the quota on output 1. The welfare effects of introducing a quota on output 2 are reflected by the change in this producer surplus. The welfare loss of the quota, $q^2$, on output 2 given the quota on output 1, is the area $v + w$. If a quota on output 2 is introduced given no quota on output 1 (but an output price on output 1 equal to the virtual price, $p_1 - \lambda_1^0$), then the loss of implementing quota 2 is area $v$, using the ordinary demand curve $D_2$. The Le Chatelier effect is clear, since there is a higher loss in quasi-rent when the second quota is introduced if a quota is present on output 1. If the spillover effects between the quota markets are small, the error when ordinary (or partial) curves are used will also be minor. The partial model will give a lower loss in quasi-rent than the general model (see figure 3 and compare area $v + w$ with the area $v$).

The analysis has been based on the case of fisheries, but for a joint in input technology the approach used is general and can be applied in cases other than fisheries.

\textsuperscript{18} Since Squires and Kirkley (1995,1996) are adding the quasi-rent from each species under quota in order to get total quasi-rent, their development of the Le Chatelier effect is based on a misinterpretation of their empirical results.

\textsuperscript{19} $(\lambda^0_1, \lambda^0_2)$ is the equilibrium quota prices given quota on output 1 and no quota on output 2, while $(\lambda^1_1, \lambda^2_2)$ is the equilibrium prices given quota on both output 1 and 2.
6. Conclusion

In this paper welfare effects of quota reforms are examined. It is found that for a multiproduct firm with a joint in input technology the welfare effects under a single quota can be measured using the inverse derived demand curve for quota. Under a multiple quota regime the welfare effects can be measured in one quota market using the inverse derived equilibrium demand function for quota.

The technology of the multiproduct firm has been assumed to be joint in inputs, that is, there are technical and economic interactions between outputs. If the technology is non-joint in inputs, then the technology can be described by separate production functions. Then, it is possible to measure the quasi-rent from each output, and hence, the total quasi-rent is the sum of quasi-rent for each output. The multiproduct firm can in this case be broken up into single-product firms, which, on the aggregate level, produce the same level of each output as the multiproduct firm using the same level of each input (Laitinen 1980). In the special case where the technology is both separable between outputs and inputs and non-joint in inputs, there are fixed proportions between outputs and hence the technology is basically a single output technology (Hall 1973). In this case the total quasi-rent can be measured in one output market (all outputs are necessary).

This framework can also be used to analyse quota reforms given that distortions exist in other markets. An example could be distortions in the labour market.

20 Under an input-output technology the output allocation decision is independent of the changes in input prices (Laitinen 1980).
which could have a significant feedback effect, because quota reforms often mean a reduction in the fleets and hence reduced employment within the fisheries. If the fishermen’s share of the labour market in fishery-dependent regions is also relatively large, then there could be important feedback effects.

References


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