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Abstract. *This paper focuses on causality in demand. A methodology where causality is imposed and tested within an empirical co-integrated demand model, not pre-specified, is suggested. The methodology allows different causality of different products within the same demand system. The methodology is applied to fish demand. On the German market for farmed trout and substitutes, it is found that supply sources, i.e. aquaculture and fishery, are not the only determinant of causality. Storing, tightness of management and aggregation level of integrated markets might also be important. The methodological implication is that more explicit focus on causality in demand analyses provides improved information. The results suggest that frozen trout forms part of a large European whitefish market, where prices of fresh trout are formed on a relatively separate market. Redfish is a substitute on both markets. The policy implication is that increased production of trout causes a downward pressure on fresh trout prices, but frozen trout prices remain relatively unaffected.*

Keywords: *Causality, ordinary demand, inverse demand, combined demand, double logarithmic demand, co-integrated demand systems, tightness of management.*

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Introduction

The purpose of this paper is to identify demand on markets where some products have predetermined prices, others predetermined quantities, and to apply this for the analysis of a market supplied by both farmed and captured fish. Demand for farmed fish has traditionally been studied using ordinary demand systems where prices are predetermined. Contrary, demand for captured fish has been studied in inverse demand systems with quantities being exogenous. Is this a proper choice or are other factors such as storing, management and aggregation level of integrated markets also decisive for causality? And should demand on markets supplied by both farmed and captured fish be modelled in ordinary, inverse or combined demand systems? This paper focuses on the choice of causality in demand. In a co-integration framework for non-stationary data[1], this paper suggests a methodology where causality is imposed and tested within an empirical demand model. Hence, pre-specification of causality in demand is unnecessary. The methodology is applied to an analysis of German demand for farmed trout and potential substitutes.

Causality in demand depends on whether the market is supplied from capture fisheries or fish farms and the reason relates to control. Marine fish farms can organise and sell their production when the conditions of the markets are favourable. Inland fish farmers do also have this opportunity, although not to the same extent, since they traditionally raise smaller fish with a shorter production cycle and with the market demanding exact small sizes of the fish. Fishermen do to an even lesser extent have this opportunity, since they have to fish when fisheries management, bio-economy and weather allow it. This implies superiority of the ordinary demand system for farmed fish and the inverse demand system for captured fish.

There are exceptions to this rule, since aquaculture production is not always fully controllable by fish farmers owing to tight environmental regulations including e.g. feed quotas. Hence, inverse demand systems might in some instances be superior on farmed fish markets. On the other hand, storing of captured fish and the potentially lose management of some fisheries point towards ordinary demand. Furthermore, the level of aggregation affects causality in demand on integrated markets. On a high level of aggregation the inverse demand system is more appropriate than the ordinary. The reason is that when prices are formed on aggregated (e.g. world markets) the price on a disaggregated (e.g. country) market take the aggregated price as exogenous. Given these factors, the choice of causality in demand is not *a priory* given and determination of causality within the model is important in economic models of fish demand.

The issue is important since causality matters, both for the subject potentially analysed and for the results obtained. Despite the theory states that the own-price elasticity in ordinary and inverse demand systems is equal when inverted for demand systems with well defined preference structures[2], studies show that prices systematically are estimated to be more sensitive to changing quantities in ordinary than inverse demand estimations (Houck 1966, Huang 1994). There are several reasons for this. First, prices are linked through the market, implying that variations of several markets might be revealed in one price. Using own price elasticities as a proxy for own price flexibilities, and *visa versa*, one commits considerable measurement errors. Furthermore, the cross-price effects of the inverse and ordinary demand systems can show different interaction. For example, ordinary demand can point towards substitutability, where inverse demand shows complementarity, as will appear below. Hence, the choice of causality matters and the effects of price shocks can only be analysed in empirical consistent ordinary demand models, where the effects of quantity changes can only be assessed in empirical consistent inverse demand models.

The present paper suggests a procedure where causality in demand is imposed and tested within the model, not specified before estimation. Also, different causalities for different products in a demand system can be imposed and tested using that procedure. The hypothesis is that theoretical and empirical consistent[3] demand systems in the German trout case identify ordinary demand equations for farmed trout and salmon, and inverse demand equations for captured cod and redfish. The expectation is that supply source might remain more important for causality than possibilities of storing and tightness of management. The expectation of superiority of the ordinary demand system is further supported for farmed trout and salmon by that Germany might be part of international integrated markets (DeVoretz and Salvanes 1993; Nielsen *et al* 2007), with German prices given exogenously by world market prices. The expectation of the superiority of the inverse demand system on captured fish markets is on this basis challenged. Germany is only a small part of international integrated markets, implying that German prices are determined on the international market. Hence, German prices might to some extent be exogenous to German demand, implying that the ordinary demand system might be suitable. If the hypothesis holds, it points towards demand for farmed and captured fish being modelled in ordinary and inverse demand systems, respectively. If, however, the hypothesis does not hold, tightness of management and for captured fish the international integration of markets might be more important for causality than supply source. The implications will then be that causality should be given more explicit focus in future analyses of fish demand.

In the economic literature, studies of demand date back many centuries and it can be argued that empirical demand analysis is the main motivation for the subject of economics. The first known empirical analysis of demand is by the Frenchman Davenant from 1699 (Stigler 1969). Stone (1954) provided an important modern contribution in the neo-classical commodity market tradition, where utility is maximised subject to a budget restiction. Deaton and Muellbauer (1980a) introduced the Almost Ideal Demand System, where costs are minimised given utility and which "permits exact aggregation over consumers and represent market demand as if they were the outcome of decisions by a rational representative consumer". These articles formed the basis for numerous more recent empirical estimations of demand (Menezes, Azzoni and Silveria 2008; Nicita 2008;, Huang, Mjelde and Bessler 2007; Goel *et al* 2006; Ford and Jackson 2004; Eakins and Gallagher 2003; Klonaris and Hallam 2003; Yen, Kan and Su 2002) including some on fish (DeVoretz and Salvanes 1993; Bjørndal, Salvanes and Gordon 1994; Asche 1996).

The articles identified ordinary demand, where another direction starting with Bell (1968) developed inverse demand systems. Anderson (1980) deduced the mathematical framework for inverse demand systems, Barten and Bettendorf (1989) introduced the Rotterdam model in its inverse form and Eales and Unnevehr (1994) the Inverse Almost Ideal Demand System.Masuda (2007) apply a linear approximation to the system to fresh food in Japan and Moro and Sckokai (2002) use inverse demand systems to estimate food demand in Italy. Furthermore, Eales, Durham and Wessels (1997) estimated both ordinary and inverse demand systems for fish in Japan. They found that for fresh products, the quantity available in any month must be consumed and so price must adjust. This led to the formulation of a system of inverse demand functions.

Where the two directions are based on a pre-specified causality in demand, Samuelson (1965) and Chapes (1984) developed the framework for mixed demand systems. Moschini and Vissa (1993) provided an example of estimation of mixed demand systems. Mixed demand systems are characterised by having prices predetermined for some goods while quantities are predetermined for others. Thereby, mixed demand creates a better framework for specifying correct causalities of demand than traditional systems, since e.g. the Almost Ideal Demand Systems assume a pre-specified causality as revealed by the variables included in the estimation.

Mixed demand systems also require knowledge of both supply and demand functions. Therefore, the identification problem of traditional econometrics, where supply and demand effects in the analysis of stationary data cannot be distinguished from each other, are solved. Different prices and quantities are, however, endogenous in the same equations, implying that price-price and quantity-quantity elasticities appear. Such elasticities are not easily interpreted and do not provide information on cross-price effects.

Where earlier studies used traditional econometrics like Seemingly Unrelated Regression, co-integrated demand systems appeared with the developments of econometrics of non-stationary data over the last decades. Thereby, the identification problem of traditional econometrics is solved, since all “exogenous” variables in co-integration analysis are lagged endogenous variables. Simultaneously, the interpretation problems of mixed demand systems disappear. Misas and Ramirez (2004) use co-integration to estimate the demand for Columbian non-traditional exports and Abbott and DeVita (2002) estimate price and income elasticties for Hong Kong exports using co-integration. Futhremore, Jaffry, Pascoe and Robinson (1999) estimated an inverse double logarithmic co-integrated demand system of high valued fish in the UK, where Attfield (1997), Kaabia and Gil (2001) and Karagiannis and Mergos (2002) estimated co-integrated ordinary Almost Ideal Demand Systems.

The present paper focuses explicitly on causality in demand, maybe as the first by applying the Juselius (2006) improved co-integration estimation techniques. A methodology identifying both ordinary and inverse demand equations, where causality in demand is identified and tested within a model, not pre-specified, is introduced. The methodology might with potential identification of both ordinary and inverse demand on the same market provide more information than obtained from traditional demand analysis. The system is not mixed in the sense that prices depend on both quantities and prices, but combined in the sense that one demand equation can be inverse, another ordinary. For the double logarithmic demand system used, a broad range of techniques to analyse markets supplied by both captured and farmed fish is introduced. These includes the identification and tests of demand systems allowing one demand equation to be ordinary and another inverse, and test of causality in the form of joint test of weak exogeneity of quantities and prices, respectively, in a demand system.

Methodology

Estimation of elasticities and flexibilities as pure numbers is often the primary aim of empirical demand analysis. With respect to demand we can distinguish between Marshallian and Hicksian demand functions. In the Marshallian demand functions income enters while utility is included in the Hicksian demand functions. Application of Hicksian demand systems always require pre-specification of causality, since different variables appear in the estimation. Provided that data are non-stationary, causality of Marshallian demand needs not necessarily to be pre-specified, since the same variables appear no matter the causality. The implication of this is that causalities of the system can be identified and tested within the Marshallian demand functions. The system also allows for different causality for different equations. In the present paper the Marshallian approach is chosen, since *a priory* it is not possible to choose a causality of the demand system. Furthermore, some products might have predetermined prices, others predetermined quantities.

Because the purpose is to estimate elasticities we follow Stone (1954) and specify the double logarithmic demand functions:

$$\log(p_i) = a_0 + \sum_{i=1}^{n} a_i \log(q_i) + a_E \log E \tag{1a}$$

$$\log(q_i) = b_0 + \sum_{i=1}^{n} b_i \log(p_i) + b_E \log E \tag{1b}$$

Where p_i is the price of good i, q_i is the quantity for good i, E is expenditure, a_i is the price flexibility for good i, b_i is the price elasticity for good i, a_E is the expenditure flexibility and b_E is the expenditure elasticity. Equation (1a) is the inverse demand function with quantities being exogenous, while equation (1b) is the ordinary demand function with prices being exogenous.

We assume that two-stage budgeting occurs in connection with equation (1a) and (1b). Two-stage budgeting implies that a constant share of the income is allocated by the consumers to product categories (Deaton and Muellbauer 1980b). After that the consumers perform utility maximisation within the product categories. With two-stage budgeting E can be interpreted as expenditures on the products that are included in the demand system.

The price flexibility is "the percentage change in the price of a good, when demand increases by one percent". An own price flexibility between -1 and 0 gives inflexible prices, where flexible prices appear if the flexibility is numerically larger. Negative cross- price flexibilities identify substitutes, where positive cross-price flexibilities identify complements. The price elasticity is "the percentage change in the demand for a good, as the price increases by one percent". An own price elasticity between -1 and 0 gives inelastic prices, where elastic prices appears for numerically larger elasticities. Positive cross price elasticities identify substitutes and negative cross-price elasticities complements. The expenditure flexibility is "the percentage change in the price of a good, as expenditures increase by one percent", where the expenditure elasticity is "the percentage change in the demand of a good, as expenditures increase by one percent". The expenditure flexibility and elasticity indicate whether a product is luxury, necessary or inferior.

Equation (1a) and (1b) are shown for stationary data. For non-stationary data co-integration must be used. Based on an I(1) nature of the data[4], the estimation of the demand system, as presented in equation (2), is performed in two steps. First, the number of co-integrated relationship is determined using the procedure in Juselius (2006). Second, the demand system is identified thereby ensuring theoretical consistency.

The procedure in Juselius (2006) is based on the Vector Auto Regressive model in equation (2):

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \ldots + \Gamma_{k-1} \Delta X_{t-k+1} + \prod X_{t-1} + \mu + \varepsilon_t \qquad (2)$$

where X_t is a column vector made up by the logarithm of prices, quantities, expenditure and a term restricted to the co-integration space. ε_t is white noise and $\prod$ is the long run solution to the Vector Auto Regressive model, which contains the possible co-integrating relations.

The choice of the number of co-integrating relations is based on the trace test of Johansen (1988). However, the trace test often suffers from a problem of size and power in small sample distributions. Therefore, Juselius (2006) recommends that the choice of the number of co-integration relations is based on as much information as possible. Such information includes the trace test besides also recursive graphs of the trace statistics, characteristic roots, significance of the α-coefficients, graphs of the co-integration relations and the economic interpretability of the results. The null hypothesis of the trace test is that up to a given number of co-integrating vectors exist, whereas the alternative hypothesis is that exactly one more co-integrating vector exists. This is tested in a standard likelihood ratio setup. The recursive graphs of the trace statistics show the stability of the rank determination, whereas the characteristic root of the companion matrix will be close to one if one unneeded co-integration relation is included. Low *t*-values of the α-coefficients indicate that one would not gain a lot by including an extra co-integration relation. The time series graphs of the chosen co-integration vectors shall be stationary, where the graphs of one more co-integration vector shall be non-stationary. Economic interpretability relates to identification of the demand systems.

In a model with *n* goods the X_t vector of size (2n+2)x1 is given in equation (3), with all variables measured in logarithm:

$$X_t = \begin{bmatrix} p_1 \\ \cdot \\ p_n \\ q_1 \\ \cdot \\ q_n \\ E \\ RT \end{bmatrix} \qquad (3)$$

where *RT* either a constant or a trend.

The rank of Π in equation (2) determines the number of stationary linear combinations of the variables in X_t. Provided that the rank is larger than zero and less than the number of variables (*n*), Π can be decomposed into $\alpha\beta'$, where β contains the long-run co-integrating relations and α the adjustment coefficients. Given the determined rank, the co-integration relations identify the demand systems. Each row in β' identifies the long-run demand equation for one product, where each column in α measures the speed of adjustment of that equation. In the present paper the rank condition of Johansen and Juselius (1994) is fulfilled in all cases. Hence, all estimated systems are over-identified, since the number of restrictions in all co-integration relations equals the total number of co-integration relations. The consequence is that the identifying restrictions for the full demand systems can be tested using Likelihood Ratio (LR) tests[5].

The restrictions are used to search for sets of demand equations which both satisfy theoretical consistency and where the LR tests of the identifying restrictions are accepted. In the present paper a rank of two is obtained in a demand system with three products (three quantity series and three price series). No well-specified models (i.e. without misspecification problems) including expenditure can be estimated. Since focus in the present paper is on trout, trout is included in all models. For a model with three goods, a restricted term and a rank of 2, the restrictions on the 2x7 sized β' matrices are shown in equation (4)-(6) for the inverse and ordinary forms, and for a combined demand system, with the first equation being ordinary and the second inverse. Two zero restrictions and a normalisation restriction around minus one are imposed on each co-integration relation. Product 1 is the product which is given focus, i.e. trout, the second good is the other products for which a demand equation is identified and the third good is included only as a substitute (or complement).

$$\beta' = \begin{bmatrix} -1 & 0 & 0 & \beta_{14} & \beta_{15} & \beta_{16} & \beta_{17} \\ 0 & -1 & 0 & \beta_{24} & \beta_{25} & \beta_{26} & \beta_{27} \end{bmatrix} \quad (4)$$

$$\beta' = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & -1 & 0 & 0 & \beta_{17} \\ \beta_{21} & \beta_{22} & \beta_{23} & 0 & -1 & 0 & \beta_{27} \end{bmatrix} \quad (5)$$

$$\beta' = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & -1 & 0 & 0 & \beta_{17} \\ 0 & -1 & 0 & \beta_{24} & \beta_{25} & \beta_{26} & \beta_{27} \end{bmatrix} \quad (6)$$

In equation (4), β_{14}, β_{15} and β_{16} are the price flexibilities for product one, and β_{24} to β_{26} are the price flexibilities for product two. β_{14} and β_{25} are the own price flexibilities. In equation (5), β_{11} to β_{13} are price elasticities of product one, β_{21} to β_{23} of product two. β_{11} and β_{22} are the own price elasticities of product one and two, respectively. Finally, in equation (6), β_{11} to β_{13} are price elasticities of product one, where β_{24} to β_{26} are the price flexibilities for product two. The own price elasticity of product one and the own price flexibility of product two in equation (6) are β_{11} and β_{25}, respectively. Each of the two co-integration vectors include in all three equations, two zero restrictions and a normalisation restriction around -1, and the systems are over-identified and testable.

In the present paper a rank of one is further obtained in demand systems with two products and a restricted term, but without expenditure. In that case, an ordinary and inverse demand equation can be identified as the first row of equation (4) and (5), removing the third and sixth column, thereby, obtaining 1x5 sized β' matrices. Again, the equations are over-identified and testable.

Where restrictions on β identify the full long-run demand systems, α determines the adjustment speed of the variables, thereby, identifying common driving forces of the demand system. Weak exogeneity of price and quantity variables provide information on pushing forces in the systems. Weak exogeneity of quantities indicates that causality in demand goes from quantities to prices (is inverse) where weak exogeneity of prices points towards ordinary demand systems. Thus, the test for weak exogeneity is a test for causality in demand.

Weak exogeneity is tested by imposing zero rows in α, thereby, identifying pre-determined variables individually. Weak exogeneity of individual variables is tested using a standard procedure (Juselius 2006). Weak exogeneity on more variables jointly, first for all prices and thereafter for all quantities, is tested by imposing the restriction below. Given the result of the present paper, where a rank of two is obtained in a model with three products and a restricted term, but without expenditure, α for the joint test is shown in equation (7) and (8), with the α-matrices being of size 7x2.

$$\alpha = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \\ \alpha_{31} & \alpha_{32} \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \alpha_{71} & \alpha_{72} \end{bmatrix} \quad (7)$$

$$\alpha = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \alpha_{41} & \alpha_{42} \\ \alpha_{51} & \alpha_{52} \\ \alpha_{61} & \alpha_{62} \\ \alpha_{71} & \alpha_{72} \end{bmatrix} \quad (8)$$

Equation (7) and (8) are, given r=2, the joint test for weak exogeneity of all three quantities and all three prices, respectively, testing the adequacy of inverse and ordinary demand systems for the models with three products and a restricted term included. The restrictions are all testable using a LR test.

Given other results of the present paper where r=1, the joint test of weak exogeneity of the two quantity and price series, respectively, corresponds to the first column of equation (7) and (8), deleting row three and six, thereby obtaining 5x1 sized α -vectors.

Demand systems for trout and other relevant fish species are identified for fresh and frozen fish, respectively. Well-specified models (without misspecification) were identified searching among models with 1-4 lags, with a constant and a trend restricted to the co-integration space and with and without eleven centred seasonal dummies. Demand systems are sought among trout as the focus and two other species interchangeable. All four species are not included simultaneously, owing to insufficient degrees of freedom. Models with three species and expenditure are sought. Provided that well-specified models were identified, further estimations were performed. If no well-specified models were identified, the expenditure variable was excluded and the test repeated. In the absence of misspecification further analysis was performed. Otherwise, the price and quantity series of one more species were removed upon a one by one basis and the test repeated with two species and expenditure. Finally, if no models were acceptable expenditure was removed and a last test performed.

The test for misspecification included autocorrelation, normality, and autoregressive conditional heteroscedasticity tests. The tests used were the multivariate LM test for first and fourth order autocorrelation in the residuals, a multivariate test of normality of the Shenton-Bowman type (Doornik and Hansen 1994) and univariate LM tests for autoregressive conditional heteroscedasticity with degrees of freedom equal to the number of lags. For the results reported below all misspecification tests were rejected at the 5% level, implying that indications of misspecification were absent. Results of these tests are not reported owing to space limitations.

The results of the present paper are obtained using CATS in RATS, version 2 (Dennis *et al.* 2005).

Data and time series properties

Data on German import of trout and potential substitutes (complements) were obtained from the Eurostat Foreign Trade Statistics (Eurostat 2004). Owing to data limitations, the present analysis only uses foreign trade data, not domestic production. The data are monthly, cover the period January 1998 to December 2003 (72 observations) and includes the fresh and frozen product forms. Data are available in volume, value and average current price for trout, salmon, cod and redfish. Summary statistics are presented in Table 1 as annual averages. [Table 1 here]

The market for fresh fish is eight times larger than the market for frozen fish. However, where salmon is the main fresh fish, trout is the most important frozen fish. Measured in value terms, redfish forms approximately 10% of both markets. Cod is of minor importance.

Salmon is the most expensive species and redfish the cheapest. Trout and cod are on the same level between the two. For each species the average price is higher for frozen than for fresh fish, although almost at the same level.

Germany is the second largest global importer of raw material of trout with 8% of the total global import on 183,000 tonnes in weight in 2002 (FAO 2002a). Japan is with 45% the main import market. Export of trout from Germany is small. The main supplier of the German market is Denmark and Spain with 40% and 33% (2003), respectively. The German import consists of three types of products; white portion-sized trout typically of 200-400 gram, red portion-sized trout typically of 600-800 gram and red salmon trout larger than 1.5 kg. As opposed to other important import countries, 80% of German import was white portion-sized trout in 2003 (Nielsen et al. 2007), which are raised in inland freshwater ponds owned by small-scale firms.

The own production of trout in Germany was 24,200 tonnes in weight in 2002 (FAO 2002b), of which 85% were small portion-sized with white meat (Eurofish 2004). The yearly per capita consumption is with 650 gram at the EU average, but German consumption differs from the rest of the EU by being mostly of small portion-sized trout with white meat.

The majority of German consumption of salmon, cod and redfish is imported. Salmon originates from large-scale sea aquaculture, primarily in Norway, cod from capture fisheries mainly by Norway, Russia, Poland and Denmark, and redfish from Icelandic capture fisheries. Salmon is red and sold large-sized, where cod and redfish are white and potentially sold in different sizes. In reality, however, most sales of the captured species are in small portions, owing to the fish stocks being heavily overexploited. Salmon is consumed mainly as fresh and smoked. Imported fresh salmon is also used for smoking in the German industry. Cod and redfish are mostly consumed as fresh fish.

Results

Well-specified models were tested for the presence of I(2) in order to avoid biased results. The multivariate I(2) rank test of Nielsen (2002), Juselius (2006) and Dennis *et al.* (2005) were used with a trend restricted to the co-integration space. The null hypothesis is the presence of a certain number of I(2) trends for a given rank. Provided that all tests are rejected there are no indications of the presence of I(2). For the results reported below, there were in the first model six variables, implying that 21 tests were performed. The presence of I(2) was rejected in all cases at the 5% level. In the second and third model there were four variables and, thus, 10 tests were performed in each model. All tests were rejected at the 5% level except one in the second model, with the excepted case rejecting the null hypothesis at a marginal 8.7% level. Hence, we conclude that I(2) trends are likely not to be an issue in the results reported below. Results of the I(2) tests are not reported owing to space limitations.

In the three well-specified models without I(2) trends, the rank is determined using the trace test, the significance of the α parameters in each co-integration vector, the characteristic and roots. Results are reported in Table 2. [Table 2]

In Table 2, the first line represents rank determination indications for the first model with fresh trout, cod and redfish included. The model is estimated with three quantities and three price series included, but without expenditure, since no well-specified models with expenditure included could be identified. Estimation is performed with two lags and a constant restricted to the co-integration space. The trace test of the null hypothesis of the rank being two or less is rejected, but the null of the rank being three or less is accepted. Hence, the trace test indicates a rank of three. The column α in Table 2 shows the number of columns in the α-matrix where all parameters are not significantly different from zero, i.e. where the *t*-values are less than 2.6. None of the parameters are significantly different from zero only in two of the co-integration relations in the first model. This points towards a rank of two, since the corresponding co-integration relations add very little to the system.

The second line represents the model for fresh trout and salmon and the third line the model with frozen trout and redfish. The two models are both estimated with two price and two quantity series and with a trend restricted to the co-integration space, but without expenditure. In both models the trace test points towards a rank of three, where significance of α parameters indicates a rank of one.

The characteristic root of the companion matrix (not reported) shall be close to one if too many co-integration relations are included. In the first model, the modulus of the *p-r* root of the companion matrix, *p* being the number of variables and *r* the rank, is 0.63 and 0.51 for ranks of four and three, respectively. Although both roots are reasonably well below one, this indicates that a model with two co-integration vectors is better than three. In the second model, the modulus of the *p-r* roots is 0.87, 0.37 and 0.21 for ranks of four, three and two, respectively. In the third model, the modulus are 0.67, 0.51 and 0.54 also for ranks of four, three and two, respectively. Hence, a rank of three is too high in both the second and third model, leaving the choice of rank between one and two.

Altogether, a rank of two is chosen in the first model, owing to significance of the α-coefficients and the characteristic roots. In the second and third models, the characteristic roots point towards one or two co-integration relations, where the significance of the α-coefficients indicate one. Hence, a rank of one is chosen in these models.

In the three models, the presence of unit roots was tested in order to ensure that all data series were integrated of the same, first, order. The multivariate test for stationarity was performed with a restricted trend used according to Dennis *et al.* (2005). The null hypothesis is the presence of stationarity of the single variables, tested using χ^2-tests by imposing unit rows in β[6]. Test results are reported in Table 3. [Table 3]

Stationarity are absent at the 5% level in all three models, since the models were selected to fulfil that claim. Hence, since all data series are non-stationary and I(2) trends are absent, all data series are integrated of the first order and further analyses can be performed.

In order to identify pushing forces and thereby causality of the demand systems, weak exogeneity is tested. Tests are performed for single variables, for all quantities and for all prices jointly. Results are presented in Table 4. [Table 4]

At the 5% level, the joint tests of weak exogeneity do not in any of the cases indicate that all prices or all quantities are weakly exogenous to the system. Hence, unambiguous conclusion on the causality of the full demand systems cannot be obtained. The test of the second model does, however, suggest that all prices simultaneously are weakly exogenous at the 4% level. This points towards causality from prices to quantity, that is, to an ordinary demand system.

The test of weak exogeneity of the individual data series indicates that both prices and quantities of trout and cod are weakly exogenous in the first model, indicating that trout and cod drives the system without being severely affected by it. Since both prices and quantities are weakly exogenous, however, no clear indication of the choice of causality in the demand system can be obtained. In the second model trout prices are weak exogenous, pointing towards an ordinary demand system. Neither quantity nor prices of fresh salmon are weakly exogenous. Thus, since salmon forms 82% of this market, trout only 5%, the causality of the full demand system remains indeterminate. In the third model both prices and quantities of trout are weakly exogenous, indicating that frozen trout drives the frozen redfish market. This is explained by trout supplying 60% of this market, redfish only 11%. With both prices and quantities of trout being weakly exogenous, no unambiguous indications of causality remain.

Based on the I(1) nature of the data, the long-run demand systems are identified and tested by imposing identifying zero restrictions on β. Several different restrictions were imposed, but only results fulfilling economic theory were reported. Hence, the sign of the own price elasticities and flexibilities shall be negative and of a reasonable size. The identified demand systems and the tests of the long-run over-identifying restrictions are shown in Table 5. Two alternative sets of restrictions are shown for each of the three models. [Table 5]

In the first model, two alternative sets of restrictions identify acceptable long-run demand systems at the 5% level. The first system is an ordinary demand system for trout and redfish, the second a combined demand system with an ordinary trout equation and an inverse cod equation. In the second and third model the inverse demand equation for trout are both accepted and both ordinary models are rejected. Thus, there are examples of identified ordinary, inverse and combined demand systems which fulfil economic theory and are accepted when tested.

The causality of trout and cod demand in the first model is as expected ordinary and inverse, respectively. Demand for redfish in the first model and for trout in the second and third are against *a priory* expectations. One reason for redfish demand being ordinary might include that regulation of the redfish fishery in Iceland, as the main supplier of the German market, is not very tight. The fishery is performed both inside and outside the Extended Economic Zone. The fishery inside the zone is managed by individual transferable quotas, but the fishery outside remain unmanaged. The fishery is performed with vessels mainly targeting species like cod, saithe and haddock, which might only fish for redfish when prices are good and fisheries opportunities for other species are limited. Another reason might be that the prices of redfish are formed on an international market, causing German prices to be exogenously given by international prices.

The reason for frozen trout demand being inverse in the third model might be related to the presence of tight environmental regulations including feed quotas in one of the main supplier countries, Denmark. These regulations limit fish farmers´ ability to increase total supply and have caused thetotal Danish trout production not to increase since 1990, as in most other countries. This leaves, however, the question of why the causality of fresh and frozen trout demand in the first and third model is different. One possible explanation might be that with limiting feed quotas, fish farmers might choose to use more of their quota on potentially more profitable fresh instead of frozen trout. Trout is sold fresh in the first hand market. If it is not possible or the prices are low, the fish might be sold to the frozen market, at least if the fish cannot be stored in the ponds.

Comparing with the test for causality in Table 4 it appears that for the second model a long-run inverse demand system is accepted (p=0.13), where the test for weak exogeneity almost accepts the causality of ordinary demand (p=0.04). Provided that a 4% level is acceptable, two different causalities appear. Thereby, prices are predetermined in the short run where quantities are predetermined in the long run. The explanation of this result remains a matter of speculation, but might be that the final products are sold at relative constant prices at the retail market in the short run. If, alternatively, only the 5% level is acceptable, only the inverse demand system of the second model is reliable.

The own price effects in the first model are all reasonable according to economic theory. For fresh trout the own price elasticity is in the range of -4 (-3.66 and -4.03) and for fresh redfish it is -0.69. The own price flexibility for fresh cod is -0.11. Hence, the price of fresh trout is elastic, the price of fresh redfish inelastic and the price of fresh cod inflexible. In the second model the own price flexibility for fresh trout is -1.01 and in the third it is -0.08 for frozen trout. Thus, the price of fresh trout is unit flexible, where the price of frozen trout is inflexible.

The cross-price effects suggest that trout and redfish are substitutes in both fresh and frozen forms (all cross-price flexibilities are negative and all cross-price elasticities are positive). Measured in the ordinary demand system fresh trout and cod are complements, but with cross-price elasticities close to zero. In the inverse form the cross-price flexibility at -0.40 suggest substitutability, but again at a relatively low level. Hence, the cross-price effect of fresh trout and cod is small. Fresh trout and salmon are complements in the inverse model, but substitutes in the ordinary. Testing the over-identifying restrictions on β, the inverse model is accepted, but testing causality on α, the ordinary is accepted at the 4% level. Hence, the relationship between fresh trout and salmon remain ambiguous.

These results indicate that frozen trout and fresh cod with inflexible prices might be part of a larger European whitefish market, where these species form only a marginal share (Nielsen *et al.* 2007; Nielsen 2005). The elastic price of fresh trout further suggests that fresh trout is sold at a relatively separate market, although with redfish as a substitute. Fresh cod demand is not very important for trout demand, where the relationship between fresh trout and salmon remain ambiguous.

Discussion

The implications of the findings are two-fold, covering economic modelling and policy issues. These are discussed below. Before this, however, methods and results are qualified in order to assess the reliability of the applied methods and the validity of the results obtained. A potential problem is that no well-specified models can be identified with expenditure properly included in the model. Hence, no expenditure effects are identified and it remains unclear whether these effects are included in the estimated parameters or not. Another potential problem is that the time series used only have a relatively small number of observations and a third that only imports, not domestic production, are included in the analysis. Including domestic production would give a picture of the total German market, not only the import market.

The implications for economic modelling of the identified causalities suggest that demand for farmed fish is not as a general rule always consistently modelled in ordinary demand systems. Furthermore, demand for captured fish cannot always be modelled consistently in inverse demand systems. Causality in demand is not *a priory* given from economic theory. Thus, the first hypothesis is not confirmed with the present data. The reason might relate to the role of other factors in determining the causality. Storability, potentially loose fisheries management and disaggregated analysis of parts of international integrated markets point towards ordinary demand. Tight fisheries management, tight environmental management of aquaculture and aggregated analysis of international integrated markets point towards inverse demand systems. Hence, instead of focussing on supply source, i.e. aquaculture and fisheries, causality in demand seems besides storability to depend more on the tightness of regulations and aggregation level of international integrated markets. Therefore, causality in demand is not *a priory* given. Thus, a procedure for identification and testability of demand systems with potential different causalities is important for reliable demand analysis. This implies that causality should be given more explicit focus in future analyses of fish demand.

The present paper suggests an estimation methodology where causality in demand is determined and tested within the model, allowing different causalities of different equations. Once demand is identified and the direction of causality established, the researcher knows the opportunities and limitations for using results in a policy context. Identified ordinary demand systems can be used for consequence assessment of price regulation, where inverse demand is reliable in assessing consequences of changing quantities. Not *vice versa*. Both types of policy assessment can be consistently made only in the case where both ordinary and inverse equations are identified, as was the case in this paper. Thus, determining the causality within the model might in several occasions reveal more policy relevant information than is obtained from traditional demand analysis.

The policy implications of the finding of elastic quantities of fresh trout in the first model indicate that the quantity of trout marketed in Germany is sensitive to changing prices. When the price increases 1%, the quantity of fresh trout falls 4%. Hence, policies aiming at affecting the fresh trout prices, directly or indirectly through the costs of production in aquaculture, have a clear and perceptible effect on the quantities of fresh trout demanded on the market.

The finding of unit-flexible and inflexible prices of fresh and frozen trout, respectively, indicates together with the estimated cross-price effects that fresh trout is sold at a relative separate market with few substitutes. Frozen trout, however, seems with the very low own-price flexibility on -0.08 to form part of a large integrated EU frozen whitefish market consisting of several other species including cod, haddock, saithe, pollack and hake (Nielsen *et al.* 2007, Guillotreau 1998). The policy implication of this finding is that a potential doubling of the production of trout in one of the main supplier, Denmark, over the next five years leaves the price of frozen trout relatively unaffected, but gives a significant downward pressure on the price of fresh trout. Hence, excess supply on the fresh market might to a larger extent than today be channelled to the less lucrative frozen market where the products can be stored. Thus, the second hypothesis holds, giving producers an incentive to shift to sell frozen instead of fresh trout.

The implication of the finding of fresh trout as a product with few substitutes, redfish being one of them, is that changing prices of fresh redfish affects marketed quantities of fresh trout. With Iceland supplying 70% of the German redfish market and trading on an EU import preference tariff of 0.6% (OECD 2003), as opposed to the Most Favoured Nation tariff of 7.5%, the EU policy on preferential access of Icelandic redfish indirectly affects the German trout market. With the cross-price elasticity of trout in relation to redfish being 1.41, the quantity of trout marketed in Germany would have been around 7 % larger without the preference on redfish import from Iceland than it is today[7]. Since the results indicate close substitution between fresh trout and redfish, the tariff policy on EU import of redfish is an influential factor on the German trout market.

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TABLE 1. **German import, annual average 1998-2003.**

	Quantity (tonnes[1])	Value (€ Million)	Share (%)	Price (€/kg.)
Fresh:				
Trout	4,529	14	4.9	3.11
Salmon	66,087	235	82.2	3.55
Cod	3,726	11	3.8	3.07
Redfish	15,245	26	9.1	1.68
Total	89,587	286	100.0	3.19
Frozen:				
Trout	6,819	21	60.0	3.14
Salmon	1,681	7	20.0	4.37
Cod	643	2	5.7	3.08
Redfish	2,052	4	11.4	1.84
Total	11,195	35	100.0	3.08

Note: 1. Product weight.

TABLE 2. **Rank determination.**

Model[1]	Multivariate Johansen tests												α
	Eigenvalues						Trace test[2]						
	1	2	3	4	5	6	r=0	r<=1	r<=2	r<=3	r<=4	r<=5	
Fresh:													
1.TCR-2-RC	0.55	0.43	0.28	0.25	0.18	0.07	157.7*	102.2*	62.6*	39.4	19.5	5.4	2
2.TS-1-RT	0.53	0.36	0.32	0.07	.	.	118.1*	64.6*	32.6*	5.5	.	.	1
Frozen:													
3.TR-SC-2-RT	0.47	0.40	0.25	0.15	.	.	110.6*	66.6*	31.4*	11.5	.	.	1

Notes:

1. T=trout, C=cod, R=redfish, S=salmon, RC=model with a constant restricted to the co-integration space, RT=model with a trend restricted to the co-integration space and SC = seasonal corrected by introducing 11 centred seasonal dummies. The numbers measure the lags at which the estimations are undertaken. All tests results reported are based on the period 1998.01-2003.12, corresponding to 72 observations.
2. * = significance at the 5% level, according to critical values known from Johansen (1996).

TABLE 3. **Multivariate test for stationarity given rank.**

Model	Rank	Price				Quantity			
		Trout	Salmon	Cod	Redfish	Trout	Salmon	Cod	Redfish
1) Fresh TCR-2-RC	2	27.61	.	26.34	16.75	18.33	.	31.04	9.94
		(0.00)		(0.00)	(0.00)	(0.00)		(0.00)	(0.04)
2) Fresh TS-1-RT	1	21.71	47.34	.	.	17.38	17.23	.	.
		(0.00)	(0.00)			(0.00)	(0.00)		
3) Frozen TR-SC-2-RT	1	10.97	.	.	28.92	25.74	.	.	8.27
		(0.01)			(0.00)	(0.00)			(0.04)

TABLE 4. **Individual and simultaneous test for weak exogeneity given rank.**

Model	Rank	Price				Quantity			
		Trout	Salmon	Cod	Redfish	Trout	Salmon	Cod	Redfish
Individually									
1) Fresh TCR-2-RC	2	6.08	.	5.16	13.30	4.52	.	3.77	18.97
		(0.05)*		(0.08)*	(0.00)	(0.10)*		(0.15)*	(0.00)
2) Fresh TS-1-RT	1	0.94	6.67	.	.	15.35	7.92	.	.
		(0.33)*	(0.01)			(0.00)	(0.01)		
3) Frozen TR-SC-2-RT	1	0.69	.	.	7.25	0.01	.	.	7.16
		(0.41)*			(0.01)	(0.94)*			(0.01)
Jointly									
1) Fresh TCR-2-RC	2	30.83				26.19			
		(0.00)				(0.00)			
2) Fresh TS-1-RT	1	6.70				22.30			
		(0.04)				(0.00)			
3) Frozen TR-SC-2-RT	1	7.54				12.92			
		(0.02)				(0.00)			

TABLE 5. **Price elasticities and flexibilities and test of the identifying restrictions on beta.**

Model and exogenous variables[1]	Rank	CR_i[1]	Trout	Salmon	Cod	Redfish	Test on β[2]
1) Fresh TCR-2-RC							
a) LQ Trout	2	1	-3.66	.	-0.07	+1.41	
a) LQ Redfish	2	2	+3.17	.	-0.99	-0.69	5.40 (0.07)*
b) LQ Trout	2	1	-4.03	.	-0.03	+1.27	
b) LP Cod	2	2	-0.40	.	-0.11	-0.66	4.81 (0.09)*
2) Fresh TS-1-RT							
LQ Trout	1	1	-1.28	+0.48	.	.	14.84 (0.00)
LP Trout	1	1	-1.01	+0.83	.	.	2.30 (0.13)*
3) Frozen TR-SC-2-RT							
LQ Trout	1	1	-15.01	.	.	+2.81	4.48 (0.03)
LP Trout	1	1	-0.08	.	.	-0.19	2.03 (0.15)*

Notes:

1. LQ is the shortening of the logarithm of the quantity and LP the shortening of the logarithm of the prices. Other shortenings are presented below Table 2.
2. Tests on beta are identifying restrictions. In all the estimated models the system are over-identified and the restrictions tested.

Notes

[1] A data series is stationary if it moves randomly around a constant mean over time (that is, mean and variance are independent of time) and is non-stationary if the value of the present observation depends on the value of former observations.

[2] Demand systems with well defined preference structures include the Almost Ideal Demand system (Deaton and Muellbauer 1980a) and the Rotterdam system (Barten and Bettendorf 1989).

[3] In the present paper theoretical consistency refers to own price effects being negative and of reasonable size.

[4] A stationary data series is said to be integrated of degree zero (i.e., I(0)). A non-stationary data series is said to be integrated of degree one (i.e., I(1)) if its first differences (the difference between two periods) move randomly around a constant mean over time and integrated of a higher order (i.e., I(z)) where $z \geq 2$, if the value of the present observation depends on the value of former observations.

[5] In the case that the system is just identified restrictions can be imposed, but no testing is involved.

[6] Several and probably most articles in the literature on co-integration use univariate tests like the Augemented Dickey-Fuller tests to test for presence of unit roots, thereby determining order of integration. Typically, by pre-testing all variables individually in levels and differences. According to Juselius (2006), however, such tests are inappropriate to identify order of integration. Multivariate tests must be used. Therefore, in the present paper both stationarity and the presence of I(2) are tested in a multivariate framework. The hypotheses of the multivariate tests for stationarity are "reversed" in relation to the Augmented Dickey-Fuller test, since the null hypothesis is the presence of stationarity. The null is accepted if p>0.05.

[7] The price of redfish would have been 70%*(7.5%-0.6%) = 4.8% higher, corresponding to a quantity of trout which was 1.41*4.8% = 6.8% higher.