Impacts of introduced aquaculture species on markets for native marine aquaculture products: The case of edible oysters in Australia

Running title: Impacts of introduced aquaculture species on markets for native products

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ABSTRACT

Economic competition between introduced and native aquaculture species is of interest for industry stakeholders since increased production can affect price formation if both aquaculture species are part of the same market or even substitutes. In this study, we focus the Australian edible oyster industry which is dominated by two major species – the native Sydney rock oyster (grown mainly in Queensland and New South Wales) and the non-native Pacific oyster (grown mainly in South Australia and Tasmania). We examine the integration of the Australian oyster market to determine if there exists a single or several markets. Short and long run own, cross price and income flexibilities of demand are estimated for both species using an inverse demand system of equations. The results suggest that the markets for the two species are integrated. We found evidence that the development of the Pacific oyster industry has had an adverse impact on Sydney rock oyster prices. However, our results show that both species are not perfect substitutes. Demand for Sydney rock oysters is relatively inelastic in the long run, while no long run relationships can be identified for Pacific oysters, reflecting the developing nature of this sector.

Keywords: Sydney rock oyster, Pacific oyster, market integration, inverse demand

JEL Code: Q21, Q22

INTRODUCTION

Economic competition between introduced and native aquaculture species is of interest for industry stakeholders since increased production can affect price formation if both aquaculture species are part of the same market or even substitutes. A wide range of studies investigated the impact of aquaculture products on markets for seafood, for example Norman-López and Bjørndal (2009), Jiménez-Toribio et al. (2007), Asche et al. (2004), Bjørndal (2002), Jaffry et al. (2000), and Gordon et al. (1993). Previous studies confirm that market interaction is greatest for 'similar' products (Asche, Bjørndal, & Young, 2001; Jiménez-Toribio et al., 2007). The existence of a long run price relationship between goods can have significant implications for the development of an industry that consists of different market segments, e.g. while one segment may increase its production, the other may lose in its market share (Jiménez-Toribio et al., 2007). However, competition may also have positive effects. For example, the existence of a larger market for aquaculture products, that are treated as similar goods, may assist the growth and promotion of all market segments compared to products with few or no substitutes (Asche et al., 2001). Moreover, as individual aquaculture products evolve and mature, markets that comprise new species become more established as consumer preferences for fish may become more complex in their interactions (Asche et al., 2001).

In this study, we focus on the case of edible oysters in Australia. The cultivation of oysters in Australia has a long history, dating back more than 120 years (NSW DPI, 2005). The two key species in Australia's predominantly domestic oyster market are the native Sydney rock oyster (*Saccostrea glometata*) and the non-native Pacific oyster (*Crassostrea gigas*), which together account for about 95 per cent of total oyster production (Love & Langenkamp, 2003). Other native oyster species include the flat oysters (*Ostrea angasi*), the northern black lip oyster (*Striostrea mytiloides*) and the milky oyster (*Saccostrea cucculata*). The Sydney rock oyster is endemic to southern Queensland and New South Wales, and has been introduced into parts of Western Australia. The Pacific oyster is cultivated mainly in Tasmania and South Australia where it was introduced in the 1950s and 1960s respectively (Mitchell, Jones, & Crawford, 2000; PIRSA, 2003), although some sterile varieties are grown in southern New South Wales. The Pacific oyster's invasive behavior of native habitats (Medcof & Wolf, 1975; Pollard & Hutchings, 1990) requires a strict regulatory separation of the two species growing areas.

Australia's oyster industry contributes about A$100 million (US$100m) to the national GDP annually and is the fourth largest aquaculture sector after salmon, tuna and pearls (ABARES, 2010). The total production of edible oysters has increased from about 8,100 tons in 1988-89 to 13,911 tons in 2011 (ABARE, 1991; ABARES, 2012 and earlier issues), nearly all of which (98 per cent) is consumed in the domestic market. This growth in production was driven by an expanding production of Pacific oysters in South Australia while the production of the Sydney rock oyster has slightly decreased over time (ABARE, 1991; ABARES, 2012 and earlier issues).

The development of the Pacific oyster industry may have contributed to this decline in production of Sydney rock oysters through its impact on price. The purpose of this study is to examine the integration of the Australian oyster market and to determine whether the market treats the two oyster species as one or separate products. By testing the existence of the Law of One Price (LOP) it can be established whether goods have the same price and thus are treated by the market as identical. We use the Johansen cointegration technique (Johansen, 1988) and the ARDL bounds testing approach (Pesaran, Shin, & Smith, 2001) to identify any relationships in the available farm gate level price time series data.

Furthermore, we estimate the short and long run own and cross price flexibilities of the two key commercial oyster species using an inverse demand model, which is more appropriate for perishable goods with inelastic short run supply such as edible oysters (e.g. Barten and Bettendort (1989)). This approach assumes that the price of edible oysters is a function of the quantities supplied.

The study is organized a follows. In the next section, we provide a background on the Australian edible oyster industry. The data and methods that we employ for the analysis are described in Section 3. We report results of our analysis in section 4, and provide a discussion of our findings and concluding remarks in Section 5.

INDUSTRY BACKGROUND

Edible oysters occur naturally on rocky shores and in estuaries along the Australian coast (Figure 1). The native Sydney rock oyster is cultured in New South Wales (NSW), southern Queensland (QLD) and on one lease in Albany, Western Australia. The second major commercial species is the Pacific oyster which is native to Japan and was deliberately introduced to Tasmania (TAS) in the 1950s (Mitchell et al., 2000) and to South Australia (SA) in the late 1960s (PIRSA, 2003). Other native oyster species farmed in Australia include the flat oysters (*Ostrea angasi*) (native in the southern states of Australia), the northern black lip oyster (S*triostrea mytiloides*) and the milky oyster (*Saccostrea cucculata*) (both native to Queensland) (Love & Langenkamp, 2003). However, production of these species is considerably smaller compared to the two major cultivated species (Love & Langenkamp, 2003).

Edible oysters are cultivated in estuaries. The intertidal change in estuaries is essential for the nutrient supply of the filter feeding shellfish (NSW DPI, 2005). The cultivation methods of oysters vary depending on the location of oyster farms. The most common techniques are tray and long-line or rail basket growing methods. While natural spat is used in combination with hatchery spat to cultivate the Sydney rock oyster (NSW DPI, 2005), spat for growing the Pacific oyster is hatchery produced. As a commercial species, the Pacific oyster has the advantage of faster growth than the Sydney rock oyster. The harvest of the stock is possible after only 18 months of seeding, while the Sydney rock oyster requires at least two and a half years to reach the smallest marketable size (NSW DPI, 2011a). Furthermore, the Pacific oyster can be harvested all year (except at spawning time), while the native species is usually harvested during the summer months.

Pacific oysters have a substantially wider temperature tolerance than Sydney rock oysters, and could potentially be grown in areas currently under Sydney rock oyster production. The spatial distribution of the Pacific oyster is regulated by the fisheries legislation in each state due to this species' invasive behavior (Medcof & Wolf, 1975; Pollard & Hutchings, 1990). The faster growing Pacific oyster can dislodge Sydney rock oyster spat, effectively out-competing it for habitat and displacing the natural population on which the industry is based. The existence of these environmental regulations can be seen as an implicit valuation of the native Sydney rock oyster to the Australian society. However, triploid Pacific oysters (a sterile, selectively breed variety) are grown in low quantities in a limited number of estuaries in New South Wales.

The quantities of edible oysters produced in each state between 1989 and 2011 are shown in Figure 2. The increase in the national oyster production is primarily due to the increased cultivation of the Pacific oysters in South Australia, which has increased substantially since the late 1990s due to increased access to new and more productive sites within Coffin Bay (Trudy McGowan, South Australian Oyster Growers Association, personal communication, October 2010). In contrast, the production of the native species slightly decreased over the same period (Figure 2).

The oyster market in Australia is mainly a domestic market due to the limited shelf life of the product. The export of edible oysters (mainly to Asia) account for about 2 per cent of the annual national production and is mainly supplied by the stocks in South Australia (ABARES, 2011). The market for the Sydney rock oysters is predominantly intrastate and capital city based, with most of the NSW product sold in Sydney and the Queensland product sold in Brisbane. Only small quantities are sold interstate (ABARES, 2010; Love & Langenkamp, 2003). In contrast, most Pacific oysters produced in Tasmania and South Australia are sold interstate, supplied to metropolitan areas such as Melbourne, Sydney, Brisbane and Perth (Trudy McGowan, South Australian Oyster Growers Association, personal communication, October 2010). Both commercial species are mostly sold in three market grades, bottle (small), bistro (medium), and plate (large) (Love & Langenkamp, 2003; NSW DPI, 2005). However, the production of premium grades has fallen due to market forces, disease and in order to maintain the cash flow in a capital and labor intensive industry (Love & Langenkamp, 2003).

The expansion of the oyster industry is restricted by the availability of new sites (Love & Langenkamp, 2003). The industry is further hampered by disease outbreaks, such as the QX disease which has affected stocks of the Sydney rock oyster on a reoccurring basis since the 1970s. The disease was last recorded in the Hawkesbury River in 2004 (NSW DPI, 2011b). The Pacific Oyster Mortality Syndrome (POMS) affected stocks of triploid Pacific oysters grown in some estuaries in New South Wales in 2010/11 (NSW DPI, 2011b). The pollution of waterways, for example caused by boat traffic, run-off from nearby agriculture (McLusky & Elliott, 2004), and sewage overflow (Brake, Holds, Ross, & McLeod, 2011), is seen as an ongoing risks to oyster farming. In addition, risk to stock health and survival are associated with strong winds, high rainfalls (dilutes essentials salts) and water conditions (temperature and pH levels) (Parker, Ross, & O'Connor, 2009, 2010, 2011). Selective breeding programs, which began in the 1990s aiming for faster growing and mortality resistant stocks, have gained in importance in both segments of Australia’s edible oyster industry. In addition to stock affects, disease outbreak can negatively impact consumers' perceptions of the product (Dedah, Keithly Jr., & Kazmierczak Jr., 2011). Public misconception of the risk post disease outbreak can also be exacerbated by unbalanced media reporting advice from official food agencies (Askew, 2009). There is also evidence that an isolated disease event has the potential to negatively affect consumer trust in the product long after the potential risk to health has been eradicated, as consumer's eliminate even acceptable food risk by avoiding the product (Askew, 2009).

DATA

For our analysis, we primarily use annual farm gate data collected by the Australian Bureau of Agriculture and Resource Economics and Science (ABARES), published in the annual Australian fisheries statistics (ABARES, 2012 and earlier issues). These data were supplemented with production and value data from Queensland (Lobegeiger & Wingfield, 2010 and earlier issues) and NSW (NSW DPI, 2010). Producer organizations in both Tasmania and South Australia were also contacted, and were able to correct some apparent errors in the production and price series derived. Since quantities produced in Queensland were reported in units of dozens and the ABARES series accounts in tons, we undertook a conversion of units. The conversion rate from dozen to tons was 0.000633, which we obtained by averaging the ratio of overlapping observations in both series. The final data sets contain a time covering the period 1989 to 2011. Earlier oyster production records are not consistently available for all states, with only Queensland having earlier records. A summary of the data used in the analysis is given in Table 1. For the analysis, all data were logged.

The ABARES, NSW and Queensland data include annual production quantities and values of other oyster species farmed in each state. However, these quantities comprised less than 5 per cent of the total production in each of the examined states and were therefore ignored (Lobegeiger & Wingfield, 2010 and earlier issues). For the purposes of the analysis, Queensland and NSW were assumed to only produce Sydney rock oysters and Tasmania and South Australia produce only Pacific oysters. The small quantities of Sydney rock oysters produced in Western Australia were also not considered.

Prices were derived by dividing the production value by the quantity produced, and converted to real values using the Australian consumer price index (ABS, 2013) with 2011-12 as the base. Real prices generally decreased over the period of the data (Figure 3), consistent with the increase in supply to the domestic market (Figure 2). Since we use annual prices for the analysis, seasonal price effects cannot be observed for the farm gate level production. Any product differentiation effects of prices such as the sale of oysters in three different grades are also ignored due to the lack of sufficient data.

Information on average monthly household earnings was available from the Australian Bureau of Statistics (ABS, 2008, 2011). While data were available at the state level, for the Pacific oysters (and to a much less extent for the Sydney rock oysters) the exact final destinations of the product was not known. Consequently, the national average household earnings was applied to all states.

METHODS

The analysis was undertaken in two main stages. First, market delineation analysis was undertaken in order to determine how many markets exist. The second stage involved estimation of the oyster demand function.

Market integration analysis

Cointegration analysis to examine price interdependencies and market delineation has been applied in a wide variety of studies relating to farmed and wild caught fish and fish products

(Asche, Bremnes, & Wessells, 1999; Asche et al., 2004; Asche, Jaffry, & Hartmann, 2007; Asche & Salvanes, 1997; DeVoretz & Salvanes, 1993; Jaffry et al., 2000; Nielsen, 2005; Nielsen, Smit, & Guillen, 2009; Norman-López & Bjørndal, 2009). A prerequisite for the test of cointegration is to verify that the price series are non-stationary and to determine the variables' integration order. We use the Augmented Dickey Fuller (ADF) unit root test (Dickey & Fuller, 1979, 1981; Said & Dickey, 1984) to assess the stationary characteristic of each price series. The ADF test captures autocorrelation in the disturbance term, and by including lagged values, the ADF formulation allows for testing higher order autoregressive processes (Dickey & Fuller, 1981). However, the relatively small number of observations in the data series necessitates a limited selection of lags in order to avoid a further distortion in the power (Ng & Perron, 1995). We applied Schwert's rule for determining the optimal lag length (Schwert, 1989), which suggested a length of 1 lag was appropriate given the frequency and quantity of data.

Cointegration between the prices in different locations or products could arise if price differentials between the locations/products were stationary. Thus, if two price series that are non-stationary in their unit roots are linearly combined and exhibit stationary properties in their residuals, it can be concluded that the markets of the two price series are cointegrated.

We use the Johansen test (1988) to explore the long run relationship between prices from the oyster producing states. The Johansen test is based on an unrestricted vector autoregressive (VAR) system in the levels of the variables and can be represented as following:

$$P_t = \Pi_1 P_{t-1} + \ldots + \Pi_k X P_{t-k} + \mu + \epsilon_t \qquad (1)$$

where P_t denotes an n × 1 vector and each of the Π_i is an n × n matrix of parameters, μ is a constant term and ϵ_t as identically and independently distributed residuals. The vector VAR model in its error correction form can be expressed as:

$$\Delta P_t = \Gamma_1 \Delta P_{t-1} + \ldots + \Gamma_{k-1} \Delta P_{t-k+1} + \Pi P_{t-k} + \mu + \epsilon_t \qquad (2)$$

with $\Gamma_i = -(I - \Pi_1 - \ldots - \Pi_i)$, i = 1, ...,k-1, and $\Pi = -(I - \Pi_1 - \ldots - \Pi_k)$. The Johansen test focuses on the examination of the Π matix with Π_k as the long run level equilibrium to (1). Moreover, matrix Π = αβ', where α represents the speed of adjustment and β the matrix of long run coefficients or the error correcting mechanism.

The Johansen technique suggests two asymptotically equivalent tests for cointegration analysis, the maximum eigenvalue test and the trace test. In our study, we focus on the trace test. The test for cointegration between the P_t is calculated by looking at the rank, r, of matrix Π_k which determines how many linear combinations of P_t are stationary. The null hypothesis of the trace test is that there are, at most, r cointegration vectors. The variables in levels are stationary if r = n. None of the linear combinations are stationary if r = 0, then Π = 0. However, if 0 < r < n, r cointegration vectors exist.

Furthermore, we test for the LOP on variables that are found to have an equilibrium relationship. This allows us to determine the degree to which the goods are perfect or imperfect substitutes. The LOP can be tested by imposing the restriction β' = (1,-1)'.

To determine any long run relationship between the prices in the oyster producing states we tested for market integration between two price series at a time. Since the available price data series only contain 23 observations, we consider the lag length chosen by the Schwarz information criterion (SIC) of optimal order to investigate the existence of a long run relationship. Consequently, we are unable to examine any short run relationships and causal relationship between the prices using the Johansen test approach.

The Johansen test focuses on cases in which the underlying variables are integrated of order one, which involves unit root pretesting and, thus, involves a further degree of uncertainty into the analysis of level relationships (Pesaran et al., 2001). Given that additional degree of uncertainty when using the Johansen test and the use of a relatively short time series we employed the bounds testing approach to analyze level relationships in time series data as described by Pesaran, et al. (2001). The bounds testing approach is here used to verify the findings of the Johansen test by examining the existence of a relationship between variables in levels which is applicable irrespective of whether the underlying regressors are purely I(0) (no cointegration), purely I(1) (cointegration) or mutually integrated (Pesaran et al., 2001). To implement the bounds testing procedure we employ a conditional autoregressive distributed lag model (ARDL) as follows:

$$\Delta P_1 = \alpha + \beta t + \gamma_1 P_{1,t-1} + \gamma_2 P_{2,t-1} + \sum_{i=1}^{m} \delta_1 \Delta P_{1,t-i} + \sum_{i=1}^{m} \delta_2 \Delta P_{2,t-i} + \epsilon \qquad (3)$$

The order, *m*, of the vector autoregressive lag in this model is determined by the SIC as shown in Table 3.

The bounds test for examining possible long run relationship among prices can be conducted using the Wald or F-test statistic to test the significance of lagged level of the price variables under consideration of a conditional unrestricted equilibrium correction model. We test for the null hypothesis that there exists no relationship in the levels between the price variables, irrespective of whether the regressors are purely I(0), purely I(1) or mutually cointegrated. Two sets of critical values are provided in Table 5 for the two polar cases which assume that all regressors are either purely I(1) or purely (0). If the computed F-statistic falls outside the critical value bounds, a conclusive inference can be derived without knowing the integration/cointegration status of the underlying regressors (Pesaran et al., 2001). However, if the F-statistic falls inside these critical bounds, inference is inconclusive and knowledge about the integration of the underlying variables is required before a conclusive inference can be made (Pesaran et al., 2001). We are testing the bounds for a model with no intercept and no trend ($\alpha = 0$ and $\beta = 0$) and for a model with an unrestricted intercept and no trend (α = unrestricted and $\beta = 0$). The critical bounds for the case of no intercept and no trend were derived from Pesaran et al. (2001) and for the case of an unrestricted intercept and no trend critical values were taken from Narayan (2005).

The ARDL bounds testing approach to cointegration of prices allows us to identify price leadership among the series. This is the case when the null hypothesis of no cointegration cannot be accepted for the dependent variable.

Demand analysis

Lack of market integration does not preclude the possibility that the supply of one species can have an impact on the price of the other. The estimation of the own and cross product flexibilities of demand provides not only insight about the demand-supply relationship for oysters in each market, but also allows us to determine whether the market treats the two oyster species as substitutes or not. Inverse demand models essentially assume that market price adjusts to clear the (exogenous) supply, and effectively represent the average revenue function. Given the production lag between the initial production decision and the time of harvest, and the highly perishable nature of the product, an assumption that supply is exogenously determined (at least relative to the current price) is realistic.[1] Quantities supplied to the oyster markets are relatively fixed and determined by the seeded stock, the growth period (18 months to 3 years depending on species and grade), and risks affecting the harvestable stock. Inverse demand models have been applied to fisheries products in many other studies (Asche, 1997; Barten & Bettendorf, 1989; Bose & McIlgrom, 1996; Burton, 1992; Eales, Durham, & Wessells, 1997; Jaffry, Pascoe, & Robinson, 1999; Pascoe & Revill, 2004), as well as studies of oyster demand elsewhere (Dedah et al., 2011; Lee & Kennedy, 2008).

Non-stationarity in prices and quantities indicate dynamics in the demand relationship, and hence prices cannot be modelled directly as a function of the quantity supplied in that period. Instead, initial changes in price with quantity change may be greater or less than the longer term "equilibrium" price given that quantity level. Previous studies of demand in fisheries have captured these dynamic effects through the use of vector error correction models incorporating Johansen's (1988) procedure to estimate long run effects directly (Jaffry et al., 1999) or error correction models that capture both short and long run effects (Pascoe & Revill, 2004). In this study, the latter approach was undertaken.

The basic form of the error correction model can be expressed as:

$$\Delta p_{k,t} = \propto + \sum_{k=1}^{K} \beta_k \,\Delta q_{k,t} + \sum_{j=1}^{(n-1)} \gamma_k \,\Delta p_{k,t-j} + \sum_{k=1}^{K} \sum_{j=1}^{(n-1)} \delta_k \,\Delta q_{k,t-j} + \lambda_k p_{k,t-n} + \sum_{k=1}^{K} \mu_k \, q_{k,t-n}$$
$$+\varphi \Delta inc_t + \textstyle\sum_{j=1}^{(n-1)} \tau \Delta inc_{t-j} + \omega inc_{t-n} + \varepsilon_{k,t} \qquad (4)$$

where $\Delta p_{k,t}$ as the change in the price of product *k* in period *t*, $\Delta q_{i,t}$ is the change in the quantity, *inc* is the average monthly household income, and *n* is the number of lags over which the dynamic processes are being assessed. Prices, quantities and income are in natural logarithms and ε is the error term.

We can interpret the estimated coefficients for β_k as the short run price flexibilities, while the ratio – λ_k / μ_k gives the long run own and cross price flexibilities. The derived sign of the cross price flexibilities indicate whether the two oyster species are treated as substitutes or complements.

RESULTS

Market integration analysis

The first stage of the analysis involved testing for stationarity in the price and quantity series, and cointegration between the price series. Using the ADF test, the null hypothesis is that the series are non-stationary. The series is integrated of order one (i.e. I(1)) if the non-stationary series in levels can be rendered stationary by first differencing. For the stationarity tests, several alternative forms of the ADF test were estimated involving various combinations of trends and/or constants or neither trend nor constant. For NSW and Queensland, the most appropriate model included an intercept and a trend, while for Tasmania and South Australia only an intercept was found to be the best specification.

The results of the unit root tests of the four time series are given in Table 2.[2] As the tests were undertaken with a small sample (n = 23), interpretation of the results was based on the comparison of the estimated t-statistic with the critical value of -2.8 (Blangiewicz & Charemza, 1990) rather than the standard ADF critical value. All four lagged price series were non-stationary using one lag, fulfilling the prerequisite for testing the cointegration of the series.

The optimal lag order for the bivariate models under both cointegration approaches was chosen using the SIC. The SIC suggested a lag order of one for all price pairs except for the pair SA and TAS, for which a lag order of two was found optimal (see Table 3). The models under both cointegration analysis approaches were tested under the assumptions of no intercept and no trend, and an unrestriced intercept and no trend.

The Johansen test suggested that there exists a long run cointegration relationship between NSW/QLD; NSW/SA; and SA/TAS (see Table 4). The ARDL bounds testing approach confimed the existence of a long run relationship between NSW/QLD; and NSW/SA. However, results were found to be inconclusive for the price pairs SA/QLD and SA/TAS (for both under the assumption of no intercept and no trend) since the F-statistic fell within the bounds of the critical values (see Table 5 and Table 6). In this case, knowledge about the integration of the underlying variables is required before a conclusive inference can be made (Pesaran et al., 2001). For both cases, we treat the results calculated in the Johansen test as a conclusive inference; that is SA/TAS exhibit a cointegration relationship, while there is no long run relationship present between QLD/SA (see Table 4).

The ARDL bounds testing approach further indicted that a cointegrating relationship only exists between NSW/QLD, NSW/SA and SA/TAS when QLD, SA and TAS, respectively, were dependent variables (see Table 6). This may suggest that NSW is the price leader for Queensland and South Australia, and South Australia leads Tasmanian oyster prices.

Given that the prices of oysters were found to be related, we tested whether the LOP holds in each relationship. As shown in Table 7, the null hypothesis of the LOP was rejected at the 5 per cent significance level for the price pair NSW/SA, suggesting that both goods are no perfect subsitutes. The opposite was found for the pairs NSW/QLD and SA/TAS, implying that the goods produced in these states are perfect substitutes. These results are not surprising since Queensland and NSW produce Sydney rock oysters and South Australia and Tasmania produce Pacific oysters.

Demand analysis

In the second part of the analysis, we estimated the own and cross price flexiblities over the short and long term. We collapsed the basic formulation of the system of equations into only two equations, one each for the Sydney rock oyster and Pacific oyster markets. Given the trade-off between the lag length and the degrees of freedom in the relatively limited time series, we tested the system by using 2 lags (n = 2) as a representation for a long run effect.

The models were initially estimated using the seemingly unrelated regression estimation (SUR) method (Zellner, 1962). In this procedure the regression coefficients in all equations are estimated simultaneously for the entire system of equations, which is asymptotically more efficient than single-equation least square estimators (Zellner, 1962). However, substantial multicollinearity was found to exist in the model, mostly as a result of the key variables primarily moving in only one direction. For example, Pacific oyster production increased over the whole period of the data, while prices of both Sydney rock and Pacific oysters declined. As a result, most parameters were found to be not significant, while some parameters had the "wrong" sign. For example, Sydney rock oysters were found to be a complement to Pacific oysters – counter to expectations, common sense and economic theory.

The models were re-estimated jointly using ADMB, a non-parametric non-linear optimization modelling package for statistical parameter estimation using Markov Chain Monte Carlo methods to derive maximum likelihood estimators (Fournier et al., 2012). Parameter constraints and a penalty parameter in the joint likelihood function were imposed to try and correct for some of the problems caused by multicollinearity in the SUR estimation. As the short run flexibilities are derived directly, non-positivity constraints could be directly imposed. The long run flexibilities are derived indirectly (rather than within the initial estimation) so a penalty function needed to be added into the objective function (i.e.

minimize the negative of the log likelihood) based on the derived long run parameter values. This does not prevent the long run cross price flexibility from becoming positive, but reduces the likelihood that the two products will be complements.

The model results (Table 8) suggest that the prices are inflexible in the short term for both species, although the short term own price flexibility for Sydney rock oysters is not significantly different to -1 (i.e. unitary). In the longer term, Sydney rock oyster prices are relatively flexibile (i.e. < -1). In contrast, both the short and long term own price flexibility for Pacific oysters was relatively inflexible (i.e. > -1). Given that there is an inverse relationship between own price elasticity and flexibility, demand for Sydney rock oysters can be described as relatively inelastic, whereas Pacific oysters face a relatively elastic demand.

Changes in quantities supplied of Pacific oyster had a significant negative impact on price formation in Sydney rock oysters in the long run but not in the short term. The negative sign of the estimated cross price flexibility coefficents denote that the goods are substitutes – higher supplies of Pacific oysters (and its own subsquent lower price) results in a decrease in the price of Sydney rock oysters. In contrast, the cross product flexibility in the Pacific oyster model is zero, suggesting that Sydney rock oyster supply does not affect the price of Pacific oysters.

Income had a significant negative impact on the price of Sydney rock oysters in the longer term, but a significant positive impact on prices in the short term. In contrast, the long run income flexibility was significant and positive. A literal interpretation of this is that Sydney rock oysters are perceived as inferior products, and as incomes rise demand shifts more to Pacific oysters. However, given that real incomes generally increased over the period of the data, this may also reflect the general increase in consumer acceptance of Pacific oyster over time and increased supply to, and consumption in, markets not previously targeted by Sydney rock oysters.

DISCUSSION AND CONCLUSIONS

The objective of our study was to investigate whether the markets for the two main commercial edible oysters species in Australia are integrated and thus if the two species are considered the same product. Similarly, we aimed to test whether the markets were delineated by state and/or species. Furthermore, we intended to examine the short and long run own and cross price flexibilities for the two commercial oyster species in order to identify any price-quantity dynamics.

We found prices of the states that produce the same species to be cointegtrated, that is QLD/NSW for Sydney rock oysters and SA/TAS for Pacific oysters. This is supported by the findings of the test for the Law of One Price which revealed that goods produced in QLD/NSW and SA/TAS are perfect substitutes, respectively. However, we further found that the price of major oyster producing states for each species, NSW and SA, also hold a long run relationship in which NSW appears to be the price leader. Yet, the products in these two states were found not to be perfect substitues which leades to the conclusion that the markets in NSW and SA are not fully integrated. This result was also refelcted in the asymmetry in the demand models, with Sydney rock oysters being adversely affected by Pacific oyster production but not vice versa.

For the Australian oyster market we can conclude that Sydney rock oysters and Pacific oysters are part of the same market, and prices of the major producing states move together. While this is the case, we need to emphasize that the spatial distribution of sales markets for each oyster species is to be differentiated from the economic definition of a market. While both species were here found to be part of the same economic market, Sydney rock oysters are predominantly sold in Queensland and NSW, while Pacific oysters are sold in Queensland, NSW, SA, Tasmania, Victoria and Asia (Trudy McGowan, South Australian

Oyster Growers Association and Tim Paice, Tasmania Department of Primary Industries personal communication, May 2013).

The estimation of the inverse demand model suggested that price adjustments to changes in quantities supplied within the Sydney rock oyster market are more responsive in the long run. In the short run, the price flexibility for Sydney rock oysters is not significantly different from unity, suggesting changes in quantity supplied have an almost equivalent impact on changes in prices received. In the long term, the own price flexibility is greater than unity (i.e. indicating a relative inelastic demand), so growth in this sector may result in a net decrease in industry revenue. Furthermore, the results suggest that the Sydney rock oyster market treats Pacific oysters as subsitutes, and hence the increase in output of Pacific oysters is likely to have had an adverse impact on Sydney rock oyster prices.

In contrast, both the short and long term own price flexibility for Pacific oysters is relatively inflexible, suggesting that prices have decreased less than proportionally with quantity produced. The long run flexibility, however, is substantially lower than unity, so that total industry revenue will continue to increase with output.

These results are also supported by recent marketing studies of consumer preferences for oysters. Loose et al. (2013) found evidence of consumer preference for Sydney rock oysters over Pacific oysters in Australia. However, they also found that species type is of low importance compared to other product attributes for consumer choice, particularly the price of oysters (Loose et al., 2013). This may explain why demand for oysters in our model shifts towards the cheaper and higher volume Pacific oysters over time, subsequently decreasing demand for Sydney rock oysters.

There have been substantial changes in the Australian market for oyster over the period of the data, with Pacific oysters contributing less than 30 per cent of total oyster production at the start of the period and 70 per cent at the end (Figure 4). The relatively elastic demand for Pacific oysters may have helped contribute to the development of the industry, as total revenue increased with production. Much of this increased production of Pacific oysters has gone to “new” markets rather than compete directly with the established markets for Sydney rock oysters. The previously established market for Sydney rock oysters is relatively inelastic, while the demand for Pacific oysters is substantially more elastic and income sensitive. There is evidence that the increase in Pacific oysters has had a negative impact on Sydney rock oyster prices. The Sydney rock oyster producers have been able to maintain their prices through reducing their own production, but given the inelastic demand this would have resulted in an overal decrease in revenue to the industry.

A major shortcoming of the study is the limited length of the time series data and the quality of the data which may have affected the quality of the results. The key state and federal agencies with responsibility for compiling such data provided all that was available. Only annual data have been compiled by these agencies in the past. While monthly price and/or quantity data from institutions along the supply chain of oysters, such as processors and wholesalers, may exist, these data are not publically available. Further, given the (geographically) widespread nature of the industry, any individual distributor of oysters may not be representative of the entire industry.

The analysis also assumes that the price of oysters is not affected by other seafood products. Of the other demand studies that explicity included oysters, one suggested that prawns, fish and other shellfish may have a significant impact on oyster prices (Lee & Kennedy, 2008), while the other (Dedah et al., 2011) estimated oyster inverse demand models independent of other seafood as we have done in this study. A priori, the expectation is that quantities supplied of other species would have little impact on oyster prices due to its unique positioning in the diet and the fact that it is almost entirely a domestic market product, and in the case of Sydney rock oysters primarily a local market.

From the model results, the development of the Pacific oyster industry has appeared to have had an adverse impact on the previously established Sydney rock oyster industry. The demand for the latter species is relatively inelastic, whereas the market for Pacific oysters faces an elastic demand, suggesting the species do not directly compete for the same set of consumers. This is directly supported by the cointegration analysis that suggests that the prices of the two species move separately. However, there is sufficient overlap to result in the growth in production of the introduced species to have had a negative impact on the market for the native species.

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ENDNOTES

[1] Preliminary models of supply suggest that the quantity of Sydney rock oyster produced in any one year is a function of the prices of Pacific oysters two and three years earlier. As Pacific oyster are still a developing industry, no meaningful supply relationship between price and quantity produced can be established.

[2] Given the potential loss of information when choosing such a short lag length (Ng & Perron, 1995), we also conducted a unit root tests with up to 4 lags to observe outcome behavior. In most cases, the results were consistent with the one lag results, although in some instances the series were identified to be I(2) with higher lag lengths.

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FIGURES AND TABLES

Figure 1: Spatial distribution of the edible oysters grown in Australia

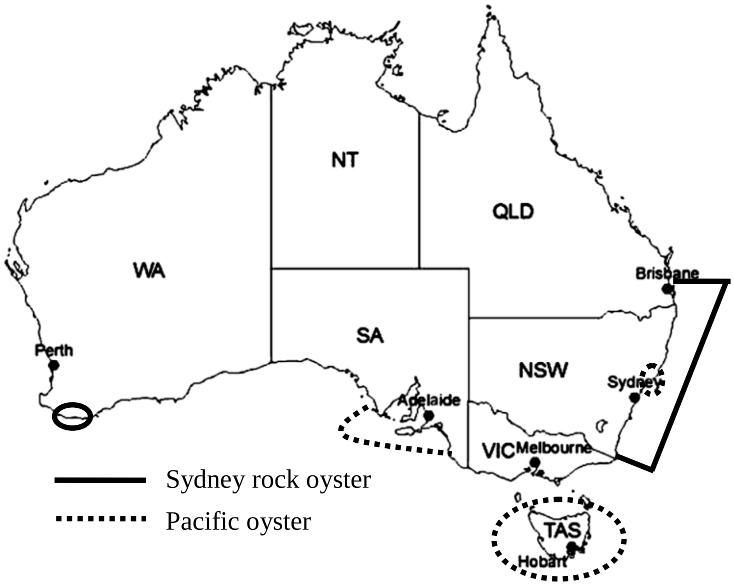
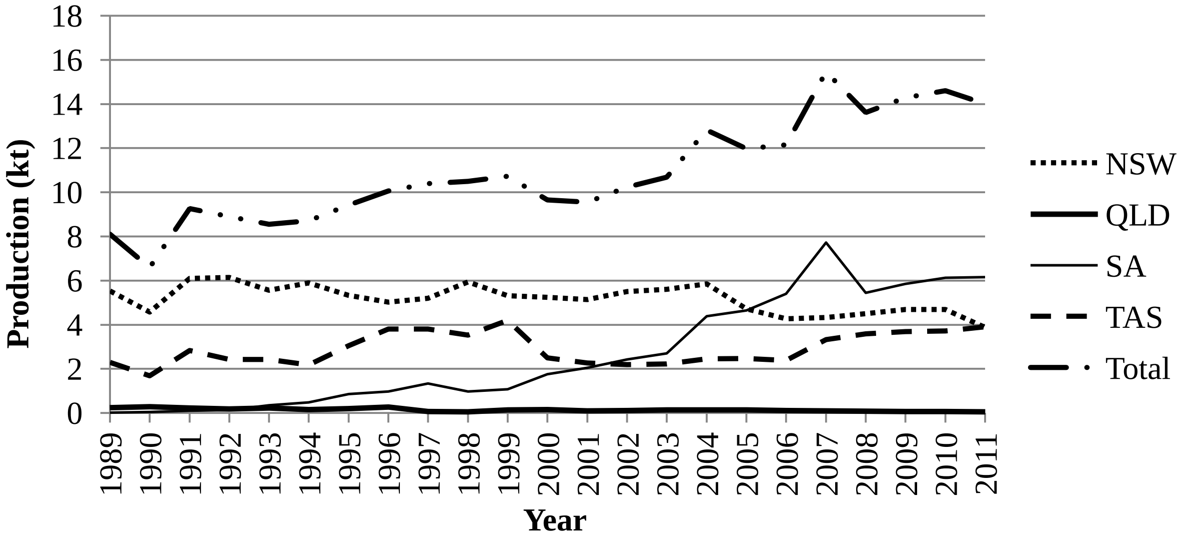
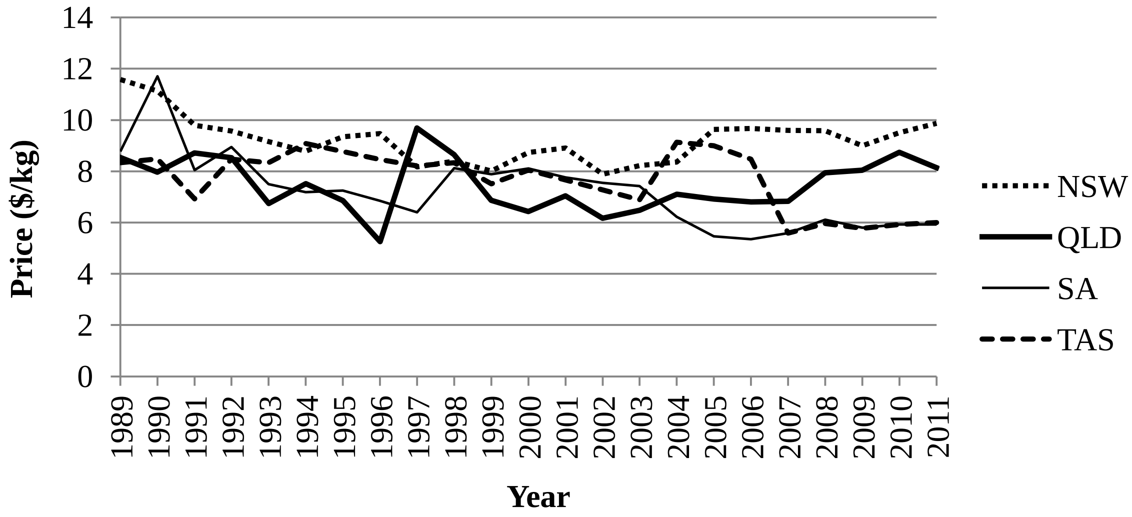


Figure 2: Edible oyster production in Australia, 1989-2011



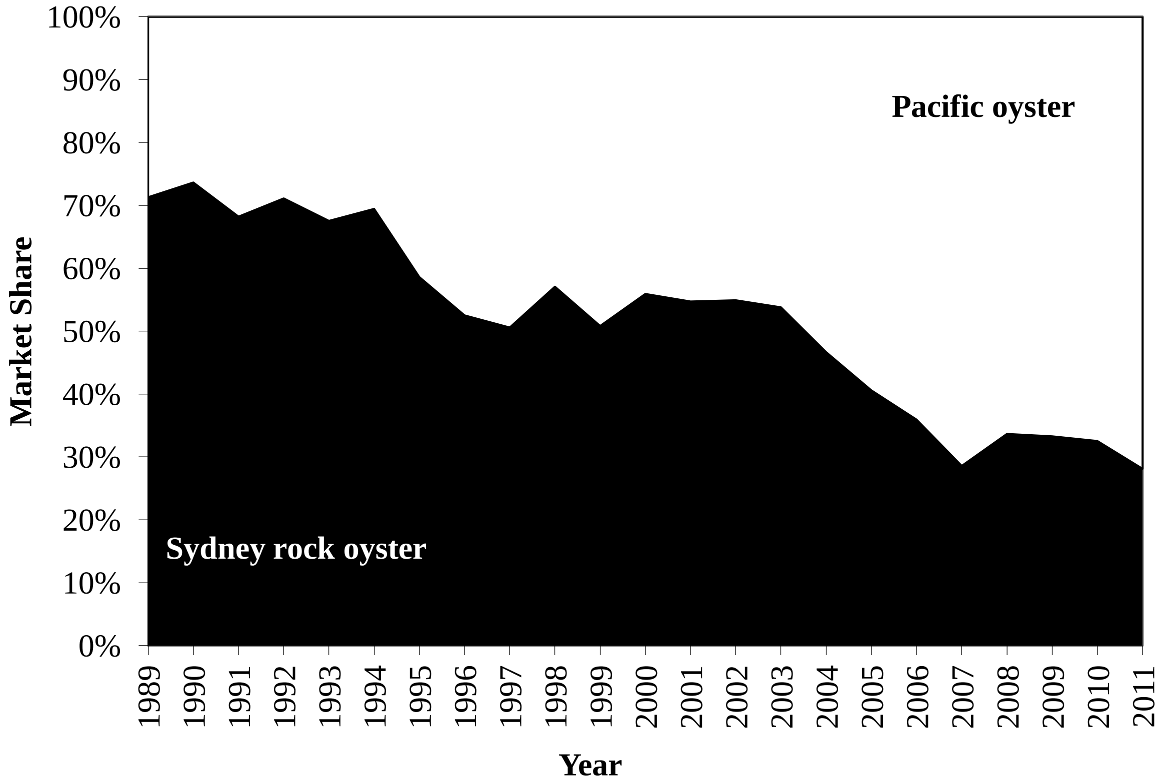
Source: ABARES (2012 and earlier issues)

Figure 3: Evolution of real prices over the period of the data



Source: ABARES (2012 and earlier issues)

Figure 4: Market shares over the period of the data



Source: ABARES (2012 and earlier issues)

Table 1: Descriptive statistics of the data used in the analysis (A$2009-11)

	Mean	Std. Dev.	Minimum	Maximum
Real Prices ($A/kg)[*]				
NSW	9.23	0.91	7.88	11.58
QLD	7.48	1.05	5.26	9.69
TAS	7.68	1.16	5.58	9.13
SA	7.21	1.45	5.35	11.70
Quantities (kt)				
NSW	5.23	0.57	4.27	6.14
QLD	0.15	0.07	0.06	0.28
TAS	2.87	0.71	0.02	7.72
SA	2.49	2.40	1.69	4.19
Real Income (A$/month)	970.38	26.09	932.95	1,021.23

Note: * A$1=US$1 (May 2013)

Table 2: Unit Root Test logged real prices for edible oysters in Australia (n = 23)

Price variable	**Assumption**	**Lag**	**Levels t-statistic**	**Levels p-value**	**First Difference t-statistic**	**First Difference p-value**
NSW	Intercept & Trend	0	-2.35	0.39	-5.25	0.00
	Intercept & Trend	1	-2.60	0.28	-3.87	0.03
QLD	Intercept & Trend	0	-3.50	0.06	-6.15	0.00
	Intercept & Trend	1	-2.77	0.22	-5.93	0.00
SA	Intercept	0	-1.80	0.37	-8.24	0.00
	Intercept	1	-2.48	0.14	-2.80	0.08
TAS	Intercept	0	-1.81	0.37	-5.52	0.00
	Intercept	1	-1.43	0.55	-3.38	0.02

Note: The t-statistic is to be compared with the critical value of -2.8 suggested by Blangiewicz and Charmeza (1990) for time series with a small sample size.

Table 3: VAR Lag Order Selection Criteria

Price pair	Lag	Schwarz information criterion
NSW/QLD	0	-3.26
	1	-3.33*
	2	-3.00
NSW/SA	0	-3.29
	1	-4.19*
	2	-4.08
NSW/TAS	0	-3.06
	1	-3.53*
	2	-2.99
QLD/SA	0	-1.75
	1	-2.23*
	2	-1.88
QLD/TAS	0	-1.67
	1	-1.73*
	2	-1.18
SA/TAS	0	-1.62
	1	-2.43
	2	-2.67*

Note: * indicates lag order selected by the criterion

Table 4: Results for the Johansen test for conintgration

Real prices	Assumption	Rank (ρ) = 0				Rank (ρ) ≤ 1		
		Lag	Trace t-statistic	Trace CV	p-value	Trace t-statistic	Trace CV	p-value
NSW/QLD	No intercept & no trend	1	16.17	12.32	0.01	0.25	4.13	0.68
	Unrestricted intercept & no trend	1	23.08	15.49	0.00	7.13	3.84	0.01
NSW/SA	No intercept & no trend	1	10.10	12.32	0.11	0.10	4.13	0.79
	Unrestricted intercept & no trend	1	23.15	15.49	0.00	2.82	3.84	0.09
NSW/TAS	No intercept & no trend	1	1.60	12.32	0.98	0.55	4.13	0.52
	Unrestricted intercept & no trend	1	12.49	15.49	0.13	0.80	3.84	0.37
QLD/SA	No intercept & no trend	1	9.64	12.32	0.14	0.36	4.13	0.61
	Unrestricted intercept & no trend	1	13.48	15.49	0.10	5.94	3.84	0.01
QLD/TAS	No intercept & no trend	1	3.20	12.32	0.82	0.43	4.13	0.57
	Unrestricted intercept & no trend	1	11.87	15.49	0.16	1.78	3.84	0.18
SA/TAS	No intercept & no trend	2	13.71	12.32	0.03	2.74	4.13	0.12
	Unrestricted intercept & no trend	2	11.25	15.49	0.20	0.11	3.84	0.74

Note: Trace CV is the critical value of the trace test

Table 5: Critical value bounds for ARDL test approach for cointegration

Assumptions (for k=1 cointegration equations, 5 per cent significance level)	**Critical Value Bounds I(0)**	**Critical Value Bounds I(1)**
Unrestricted intercept & no trend [Narayan, 2005]	5.395	6.35
No intercept & no trend [Pesaran et al., 2001]	4.650	5.150

Table 6: Results for the ARDL bounds test for conintgration

Assumption	Lag order*	Price pairs	Wald test F-statistic	Results	Interpretation of results
Unrestricted intercept & no trend	1	NSW/QLD	4.310	I(0)	No cointegration
	1	QLD/NSW	8.549	I(1)	Cointegration
No intercept & no trend	1	NSW/QLD	1.251	I(0)	No cointegration
	1	QLD/NSW	8.731	I(1)	Cointegration
Unrestricted intercept & no trend	1	NSW/SA	4.860	I(0)	No cointegration
	1	SA/NSW	6.939	I(1)	Cointegration
No intercept & no trend	1	NSW/SA	0.243	I(0)	No cointegration
	1	SA/NSW	5.182	I(1)	Cointegration
Unrestricted intercept & no trend	1	NSW/Tas	4.113	I(0)	No cointegration
	1	TAS/NSW	2.228	I(0)	No cointegration
No intercept & no trend	1	NSW/Tas	0.235	I(0)	No cointegration
	1	TAS/NSW	0.388	I(0)	No cointegration
Unrestricted intercept & no trend	1	QLD/SA	3.447	I(0)	No cointegration
	1	SA/QLD	2.618	I(0)	No cointegration
No intercept & no trend	1	QLD/SA	0.205	I(0)	No cointegration
	1	SA/QLD	4.663	-	Inconclusive
Unrestricted intercept & no trend	1	QLD/TAS	4.777	I(0)	No cointegration
	1	TAS/QLD	0.849	I(0)	No cointegration
No intercept & no	1	QLD/TAS	0.597	I(0)	No cointegration
	1	TAS/QLD	0.655	I(0)	No cointegration
Unrestricted intercept & no trend	2	SA/TAS	0.873	I(0)	No cointegration
	2	TAS/SA	4.203	I(0)	No cointegration
No intercept & no trend	2	SA/TAS	1.653	I(0)	No cointegration
	2	TAS/SA	4.991	-	Inconclusive

Note: * based on the Schwarz information criterion (see Table 3), the F-statistic of the Wald test is to be compared to critical value bounds in Table 5

Table 7: Results for the test of the Law of One Price

Cointegrated price pair	**Lag order***	**LR Statistic**	**p-value**
NSW/QLD	1	0.002	0.961
NSW/SA	1	14.810	0.000
SA/TAS	2	1.302	0.254

Note: * based on the Schwarz information criterion (see Table 3)

Table 8: Estimated inverse demand estimations – non parametric estimation

Sydney rock oyster ($\Delta p_{SRO,t}$)			**Pacific oyster ($\Delta p_{PO,t}$)**		
Coefficient	**Coefficient estimate**	**Std. Error**	**Coefficient**	**Coefficient estimate**	**Std. Error**
α	23.524	7.090***	α	-9.246	5.337**
β_{SRO}	-0.804	0.170***	β_{SRO}	0.000	0.000
β_{PO}	-0.008	0.043	β_{PO}	-0.262	0.050***
γ_{SRO}	-1.134	0.209***	γ_{PO}	-0.682	0.218***
δ_{SRO}	-1.090	0.255***	δ_{SRO}	-0.124	0.078**
δ_{PO}	-0.051	0.055	δ_{PO}	0.399	0.144***
λ_{SRO}	-0.938	0.172***	λ_{PO}	-0.382	0.172**
μ_{SRO}	-1.275	0.328***	μ_{SRO}	-0.135	0.048***
μ_{PO}	-0.138	0.058***	μ_{PO}	0.315	0.204***
φ	2.615	0.613***	φ	-0.046	0.715
τ	1.586	0.669***	τ	-0.006	0.691
ω	-1.382	0.698**	ω	1.236	0.709**
Long run flexibilities					
$-\mu_{SRO}/\lambda_{SRO}$	-1.359	0.184***	$-\mu_{SRO}/\lambda_{PO}$	0.000	0.000**
$-\mu_{PO}/\lambda_{SRO}$	-0.147	0.045***	$-\mu_{PO}/\lambda_{PO}$	-0.353	0.136***
$-\omega/\lambda_{SRO}$	-1.473	0.703**	$-\omega/\lambda_{PO}$	3.239	2.115*

Notes: *** significant at 1% level, ** significant at 5% level, * significant at 10% level.