2015

Three Essays on Shellfish Management in Rhode Island

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THREE ESSAYS ON SHELLFISH MANAGEMENT IN RHODE ISLAND

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

ENVIRONMENT AND NATURAL RESOURCE ECONOMICS

UNIVERSITY OF RHODE ISLAND

2015

DOCTOR OF PHILOSOPHY DISSERTATION

OF

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2015

ABSTRACT

Shellfish resources are the main fishery resources commercially harvested and cultured in Rhode Island. Wild shellfish management in Rhode Island is undertaken by the RI Department of Environmental Management (DEM) aiming to achieve, among other objectives, conserving naturally occurring shellfish populations in RI waters and managing public health outcomes due to, water quality issues. However, for any management scheme or regulation to be effective, policy must recognize the economic forces at work when evaluating proposed intervention or regulation of shellfishing. Regulations would influence the harvesters' behavior through the change in the harvested quantity or market price of the product and this will affect the state of shellfish stock. As such, ignoring the market force could not only nullify the management effectiveness but could backfire and lead to unintended adverse impact on the primary target of management—the healthy stock of shellfish. Moreover, some of the regulations for shellfish resources might also affect the public. For example, people value houses near to the coast due to the aestheticism and serenity. However, construction of oyster farms near their backyard water might affect their view and calmness due to the frequent traffic in the water, which might decrease the value of those houses. Since the problem is directly linked to public, it is critically important to analyze whether regulations affect the houses and life of the coastal region. This dissertation addresses three research questions related to the management of shellfish resources in Rhode Island.

In the first manuscript a market study was conducted to study the price and quantity relationships of commercially harvested shellfish in Rhode Island. The study

analyzed the price sensitivity of shellfish products (three different market categories of quahog, scallops, and whelk) with respect to quantity landed of its own and other products using non-linear Almost Ideal Demand System (NL-AIDS) model. The study shows that the shellfish products considered in the analysis were price inflexible indicating that a significantly huge quantity of shellfish is required to change the price of the species. The study also showed that the shellfish species are substitutes to each other.

The second manuscript measures the economic performance of shellfish transplant program conducted in some of the fishing areas to enrich the stock of quahog in Narragansett Bay area. The RI Department of Environment and Management (DEM) collect quahog from prohibited fishing areas with the help of fishermen and transplant to some of the selected open fishing areas. Using commercial harvest data of quahog from the bay area, the study investigated effect of transplant of quahog on quantity harvested and stock population in Narragansett Bay area. Moreover, profit from the transplant program was calculated to examine its net returns. The study showed that there is no statistical evidence to prove that transplantation is significantly influencing the harvest of quahog in Narragansett Bay area. The net returns estimates suggest that the transplant operation is not profitable.

The third manuscript analyzes the effect of aquaculture on the public by looking at the impact of construction of oyster farms on the neighboring housing value in Rhode Island, using housing sale transaction data of Rhode Island from 2000 to 2012. The difference-in-difference method was combined within a Hedonic price model to evaluate the effect of farm construction occurring over time. The result showed that housing value is unaffected by construction of oyster farms in the neighborhood. This points to an important policy implication that people do not consider construction of oyster farms while purchasing property. The lack of consideration might be due to two reasons, first they consider only characteristics that are directly linked to their daily life, and secondly they might be actually supporting eco-friendly operations such as farms in their neighborhood.

ACKNOWLEDGEMENT

I would like to sincerely thank my major professor Dr. Hirotsugu Uchida for his guidance, understanding, patience, and most importantly friendship during my graduate studies at University of Rhode Island. His mentorship was paramount in shaping me as a researcher. He encouraged me to think independently and always want me to solve the problems by myself. I would also want to give my sincere thanks and appreciation to my co-major professor Gavino Puggioni for his patience, timely advice and support, and friendliness. He always supported and guided me while I was going through the most difficult life decisions.

I would also thank my core dissertation committee members Thomas Sproul and Jeremy Collie for the help and support they have provided me throughout my graduate studies. I would also want to thank Dr. James Opaluch for his critical reviews and suggestions for my dissertation. I was always supported and inspired by my friends in the department of Environment and Natural Resource Economics especially Jasmine Hwang, Edson Okwelum, Kyle Montanio, Andy Boslett, and Nathaniel Merill.

I would like to extend my gratitude to Department of Environment and Management staffs esp. Anna Webb, Jeff Mercer, Dennis Erkan, and Jason McNamee for their support and in providing appropriate data for analysis. Dave Buetel, Coastal Resource Management Council and Dale Leavitt, Roger Williams University always helped me to give more insights about the fishing industry of Rhode Island. I would also thank Rhode Island Shellfish Management Plan team to give me the opportunity to work for them to determine the price sensitivity of quahog in RI.

Most importantly I would like to thank my wife, Mini Thottathil Jose. Her consistent support, encouragement, patience, and unending love gave me enough strength to move forward and shape up my career. She along with my Son Pranav R. Pratheesh always was a helping hand whenever I needed. Last, but not least I would like to thank my parents, Sudhakaran Nair and Omana Amma for their faith in me and for always allowing me to be as ambitious as I wanted.

I dedicate this dissertation to my lovely wife,

Mini Thottathil Jose,

who embraces my life with inspiration and perseverance

PREFACE

This dissertation adopts the form of manuscript format and consists of introduction, three manuscripts, conclusion, and appendices. The overall goal of this dissertation is to analyze economic aspect of different issues pertaining to shellfish resource management in Rhode Island. The first manuscript examines the sensitivity of price of different commercially harvested shellfish with respect to the quantity landed of its own and other related shellfish products. This manuscript describes the importance of studying the price sensitivity and its relevance to policy implications.

The second manuscript investigates the economic performance of the transplant program, a management measure adopted by the state to enrich quahog stock population in Rhode Island. Using harvested quantity data, the study is analyzing the effect of transplant on harvested quantity. It also explore the economic efficiency of transplant program.

The third manuscript details the effect of culture of shellfish in the neighborhood. It inspects the change in the value of property with construction of oyster farms in the vicinity. The manuscript describes the hedonic price model and difference-in-difference model which were used to estimate the effect of change in the value.

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INTRODUCTION

Bivalve shellfish (e.g., clams, mussels, oysters) is increasing steadily in recent years. The increasing demand for seafood and increasing aquaculture operations throughout the world resulted in bringing more seafood species to the market, and bivalves are one such group (Rees et al. 2008). Bivalve shellfish production is steadily increasing throughout the world since 1990 and constitutes 10 % of the total world fish production in 2010 (Rees and World Health Organization 2010). Bivalve production consists of commercial catch from open waters and aquaculture operations. In United States bivalve production saw a steady increase of 4% of total seafood production in 2013 from 1 % of total production in 1997 (Lowther and Liddel 2013). The production data from the National Marine Fisheries Service and Rhode Island Coastal Resource Management Council shows that the production of shellfish in Rhode Island saw an increase from 2 million pounds to 3.5 million pounds.

The recent increase in the demand for shellfish has given more fishing pressure to the stock population, and without managing the resources, it could lead to over exploitation. There have been efforts in almost all countries to manage the resource. Most of the management strategies aiming for conservation are either restricting the fishing practices or restocking. Culturing of shellfish also helps in improving the stock populations by providing juveniles for restocking and adult shellfish from aquaculture farms. However, like any other culture practices, aquaculture needs to be regulated so that the culture practices does not affect the public.

In Rhode Island, wild shellfish is managed by the RI Department of Environmental Management (DEM) based on advice and recommendations of RI

Marine Fisheries Council. The management is aimed to achieve, among other objectives, (a) conserving naturally occurring shellfish populations in RI waters, and (b) protecting public health from water quality problems. One of the main management strategies adopted by the state is area closures that ban shellfishing in fishing areas with poor water quality. Closures are set where water quality is determined to be poor, as well as in the event of heavy rainfall and urban runoff that temporarily pollutes the coastal water. Another management strategy adopted by DEM is to enrich the quahog population in the Bay by transplanting quahogs from restricted/closed to open fishing areas. The upper bay area near Providence, for example is permanently closed to shellfishing due to water pollution, which effectively acts as a protected area. The quahog populations in this area is strong, and portions of them are periodically transplanted to lower bay areas where water quality is better. After allowing natural depuration for six month by closing the transplanted area, these quahogs are made available for harvesting. Transplanting may help fishermen to harvest more quahogs, as well as contributing to sustainable stock of quahogs throughout Narragansett Bay.

Shellfish aquaculture, on the other hand, is managed primarily by Coastal Resource Management Council (CRMC). The main cultured shellfish in RI are oysters and mussels, even though oysters account for the majority of the production share (Beutel 2014). CRMC, after consulting with DEM regarding the water quality of the area to be farmed, will lease out different culture sites throughout the state. The number of farms in RI increased from 2 in 2002 to 55 in 2014, indicating the rapid expansion of aquaculture (Beutel 2014).

For any management of natural resource to be successful, the authorities need to consider both biological and economic impacts of the strategy. It is important to consider that for any management scheme or regulation to be effective, policy must recognize the market forces at work. This is because the regulations that affect the market price will, in return, influence the harvesters' behavior and this will affect the state of shellfish stock. As such, ignoring the market force could not only nullify the management effectiveness but could backfire and lead to unintended adverse impacts on the primary target of management—the stock of shellfish.

The overall objective of this dissertation is to analyze the economic aspect of the three different management issues pertaining to shellfish fisheries and aquaculture management, using Rhode Island as case study. The first manuscript analyzes the impact of landing volume of own and other shellfish species on their ex-vessel prices. An example for the importance of the study is to examine the effect of the change in the landing volume of shellfish due to the closure of some of the fishing areas on its price. Since price of a product is determined in a market reflecting all sorts of variables, including fluctuations in landed volume and consumer demand as well as the influence of other seafood products, understanding how these variables interact with one another and with managerial interventions is critical. This study is the first step towards a better understanding of how the management interacts with the market through economic analysis of the Rhode Island shellfish market, which is essential to guide and support shellfish management policies in Rhode Island. Using a non-linear Inverse Almost Ideal Demand System (NL-IAIDS) model and harvest data of all shellfish in Rhode Island, the study investigated the relationship between the price of quahog and its quantity landed, and the relationship between prices of quahog and other closely related products.

The second manuscript looks at how the quahog transplant program conducted in Narragansett Bay area enhances the stock and harvest levels of quahog. Without the evaluation of economic performance of the conservation measures, it is difficult to assess the success of these measures. The success of transplant operations depends on the returns obtained from harvest of additional quahogs. Since there is no direct data regarding the harvest of transplanted quahogs, we first analyze the effect of transplanting quahogs on the harvested quantity of quahogs from the bay area. Using the model, we predict the quantity of harvest obtained from transplantation. This predicted quantity of transplant was used to calculate total revenue from the transplant operation. Net returns was calculated by deducting the total revenue from the total cost of transplant operation.

The third manuscript analyzes how the intensification of aquaculture practices in Rhode Island is affecting the value of the neighboring housing properties. The shellfish aquaculture was highly supported by the public due to its least environmental degradation and help improving the water quality. However, recently there was some resistance from the public for leasing the aquaculture sites in their vicinity, based on the perception that their house value will be degraded by the construction of oyster farms. Since the claim is directly affecting the life of public, it is critically important to study the impact of shellfish aquaculture farms on the property value. Using the housing transaction data in Rhode Island and information about the aquaculture farms leased out in the state, the study analyzed the impact by looking at the difference in the housing value before and after the construction of oyster farms. A difference-in-difference model was used within a Hedonic Price model to differentiate the change in housing price due to other characteristics from the construction of oyster farms. The distance of the property to the coastline was the variable we considered to be directly related to oyster farm development in this study, assuming that the houses near to farms will experience more negative impact than the houses located further away.

The results from this dissertation have strong policy implications. The outcome from the first manuscript suggests that the price of shellfish in Rhode Island market is price inflexible, meaning that the price will not respond proportionately to the change in quantity landed, contrary to the beliefs shared by many quahog shellfish fishers. Furthermore, cross-price sensitivity shows that all the products are substitutes to each other. These results suggest that regulators can open and close the fishing areas without being overly concerned about its impact on ex-vessel market price.

The result from the second manuscript suggests that there is no statistical evidence to prove that transplantation have significant influence on harvest of quahog in Narragansett Bay area. However, the net returns calculation suggests that based on the current data, the transplant operation is profitable in economic terms. The result from the third manuscript suggests that there is no statistical evidence to prove that the housing value is influenced by the construction of oyster farm. However, further study need to be conducted with information other than from housing transaction data because the sale transaction data only capture the perception of the house owners who enter the market.

MANUSCRIPT-1

Demand Analysis of Wild Harvested Shellfish in Rhode Island

To be submitted to Marine Resource Economics

by

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Abstract

Management of wild shellfish harvest in United States has been done through a series of opening and closing of fishing areas. However, these openings and closings inevitably had influenced the market, particularly the ex-vessel prices that harvesters receive. Without a better understanding of shellfish market, it is impractical to determine the impact of management policies on the market as well as the fishery resources. Using Rhode Island data, this study aims to understand and quantify the market interactions of wild harvested shellfish products in Rhode Island. Specifically, we estimated the sensitivity of ex-vessel prices of shellfish products (three market categories for quahog, scallop, and whelk) with respect to the quantity landed both of itself and other products. The data were obtained from Statistical Atlantic Fisheries Information System (SAFIS) and analyzed using Non-Linear Inverse Almost Ideal Demand System (NL-IAIDS) to estimate the price sensitivity of shellfish. We found that ex-vessel prices were inflexible to the variation in quantity landed, however the magnitude of sensitivity varied across products: most sensitive was necks and least sensitive was cherrystone. Yet another finding from this study was that shellfish products included in this study were all substitutes to each other. However, the magnitude of the relation varies with products. Our result showed that the relationship was stronger between necks and cherrystone quahog and least affected between cherrystone and scallops. The result also found that all the shellfish were necessity goods indicating the importance of shellfish in the state.

1.1 Introduction

Inconsistency in the flow of product to the market followed by sudden closure of some of the most productive shellfish fishing areas will create price volatility to the products. After the announcement of the closure decision, the fishermen would find it difficult to provide enough shellfish to the market. This would affect the fishermen in two ways: 1) losing their revenue for not selling the products to the market; 2) more competitors from other states in future. The market will react to the inconsistencies in product flow in the form of price change. Following the announcement of closure for shellfish harvest area, the dealers would sense the drop in the supply of product. To meet the consumers' demand the dealers would be prompted to buy shellfish from other states. On the other hand, when the harvest areas are opened after the closure event, the local fishermen will bring more products to the market. The sudden over pour of the products from the desperate fishermen will force the market to bring down the ex-vessel price of shellfish. Thus, the irregular product flow would affect the fishermen through reduced revenue and through reduced unit price by bringing more out-of-state competitors to the market.

The closure of the fishing area and its impact on fishermen revenue has always been an issue of debate between the industry and management authorities. From the fishermen's perspective, it is critically important to understand the economic aspect of shellfish resources in addition to the biological aspect before framing a management policy. The management authority usually focuses on protecting and managing the shellfish resource but as per the legislation (State of Rhode Island General Law RIGL 20 3.2 3 Freedom to Fish), the economic or market value aspect of the resources to fishermen need not to be considered while framing policy. However, it is true that for any management scheme or regulation to be effective, policy must recognize the market forces at work when evaluating proposed intervention or regulation. This is because the regulations that affect the market price will, in return, influence the harvesters' behavior and this will affect the state of shellfish stock.

Wild shellfish management in Rhode Island is undertaken by the RI Department of Environment and Management (DEM). Through its management strategy, DEM clearly recognizes that controlled opening and closing of shellfish fishing areas will in part help to meter the flow of product to the market such that prescribed biologically-safe total landings could be spread across the fishing season as much as possible. This would help the products to be available in the market throughout the season and thereby stabilizing the market price benefiting both consumers and harvesters. In reality, achieving a steady flow of shellfish to market is often disrupted due to the water quality and public health concern-related closures of fishing areas. This complicates the DEM's effort in trying to stabilize the products flow and their market price.

The challenge for DEM is to frame a sensible strategy for opening and closing of shellfish fishing areas while minimizing the price volatility of shellfish in the market. The price of a product is determined in a market reflecting fluctuations in resource availability and consumer demand as well as the influence of other seafood products. Understanding how these variables interact with one another and with managerial interventions to determine the price of shellfish is critical.

This study is the first step towards a better understanding of how the price and quantity interact within the market in short term through economic analysis of the Rhode Island shellfish market, which is essential to guide and support shellfish management policies in Rhode Island. Looking at the short-term price relationships in the market, immediate response of the price to the changes in quantity can be analyzed due to the sudden changes in the market. Using the quantity and value of the shellfish harvested in Rhode Island, we studied the price-quantity relationships of the product and its relationship between closely related products. Specifically, we estimated the own-price flexibility and cross-price flexibility for each of the shellfish harvested in Rhode Island. Of the different shellfish species harvested in Rhode Island we considered quahogs, scallops, and whelk in this study. Considering different market categories of quahog as separate market products along with other shellfish species, a system of five seafood products was used to estimate price flexibility.

In order to understand the ex-vessel market of the wild-caught shellfish, we need to focus on two aspects of the market relationship of a product.

1) The relationship between the price of a shellfish and its quantity landed;
2) The relationship between prices of a shellfish and to the quantity of other closely related products.

The first objective is directly related to a situation where the opening and closing of a shellfish harvest area triggers a large fluctuation of landing volume, affecting the ex-vessel price. To understand this relation, we estimated own-price flexibility, which measures the effect of price caused by the change in its own quantity harvested, by measuring the percentage change in price due to a percentage change in landed quantity. We estimated own-price flexibility for each of the seafood products we considered for the study, including three different market categories of quahog.

In addition to its own landing volume, the price of quahog may be affected by the landing volume of other closely related products—this is what the second objective is set to analyze. The direction of the change in price, in part, depends on whether the relationship is complementary or substitutive, and cross-price flexibility was estimated for scallops, whelk, and different market categories of quahog.[1]

In this study we used a Non-Linear Inverse Almost Ideal Demand System model (NL-IAIDS) to analyze and estimate the demand of shellfish in Rhode Island. Inverse Almost Ideal Demand System (IAIDS) have been widely accepted and used in economic literature for analyzing the demand of perishable goods such as fruits and vegetables, meat products, and seafood. However, IAIDS uses a linear approximation of the original model to make the computation easier. Recently some of the economic literature started using NL-IAIDS models for analyzing the demand in order to avoid any bias resulting from the approximation of the non-linear component.

This study will contribute towards the literature in two ways. First, this study will be the first market study in Rhode Island and the result can be used as baseline information about the shellfish market and its price-quantity relationship. Second, we are comparing the estimates obtained from non-linear IAIDS with the conventional IAIDS to measure of the accuracy of non-linear model. A few studies have used the

[1] Two other important shellfish available in Rhode Island are oysters and blue mussels. However, the majority of their production is attributed to aquaculture, which we were unable to obtain sufficient data to conduct the analysis. The inclusion of these important market products is therefore left for future study.

non-linear model for demand estimation recently, but none of the studies compared the model with conventional inverse demand model.

The results of this study give interesting information about the shellfish market in Rhode Island. The study found out that all the shellfish species considered in this model are price inflexible and indicates that price change with a unit change in the quantity is less than proportional in the short term, which supports the findings of Barten and Bettendorf (1989). The result also showed that all the shellfish species considered are substitutes to each other. The income flexibility measure shows that all these shellfish species are necessary goods. A comparison of the non-linear IAIDS model and IAIDS model was conducted, but the result showed that there is no significant change in the mean and variance of the estimates from these models. The result shows that a much complicated non-linear model is not necessary to obtain an unbiased estimate of the share equations.

This paper has been organized as follows: A brief description of an overview of shellfish industry in Rhode Island is given in Section 1.2. Section 1.3 annotates the previous studies conducted in similar areas followed by the theoretical model adopted for this study. In section 1.4, data used in the study is concisely described. The empirical model used in the study is described in section 1.5 and estimation results are summarized in section 1.6. Results of the simulation are summarized in section 1.7 and a discussion and conclusion of the study is included in section 1.8.

1.2 Overview of Shellfish Industry in Rhode Island

Seafood industry is one of the industries contributing heavily towards the economy in Rhode Island. Excluding the production from aquaculture practices, dockside value of $60.4 million was received from the seafood harvested to Rhode Island ports in 2010 and 65% of the dockside value consisted of shellfish species (Hasbrouck et al. 2011). In 2012, 83 million pounds of seafood worth of $ 80 million was reported as total seafood production (NMFS 2012). Among the total production, bivalves contribute 2.7% of the total volume which is equivalent to a value of $ 18 million. Among the different bivalve species harvested in Rhode Island, quahog and scallops each account for more than 40% of the production. On the other hand, oyster tops among the cultured shellfish in the state with a production of 6 million pieces in 2013 (CRMC 2013).

Species harvested and their markets

The important bivalve species commercially harvested from open waters of Rhode Island comprises of quahog, scallop, and soft shell clams. Quahog is considered as the most significant shellfish species harvested from open waters. In market it is categorized into four depending on its size namely, Littleneck, Topneck, Cherrystone, and Chowder. Littleneck is smallest in size followed by topneck; both commonly called as “necks” and are mainly marketed as half-shell raw products. Cherrystones are intermediate in size and are mainly utilized as cooked clams. Chowders being biggest in size are chewy and are usually used to make clam chowders after mincing. Due to the difference in utility and consumption, the market categories fetch different price in the market. Sea scallop and bay scallops are the two scallop species harvested in Rhode Island. Among the two, sea scallops are the bigger in size and are harvested more. The adductor muscles in scallops will grow to significant size and are usually called “eye”. In United States, the scallops are processed and only the adductor muscles are marketed. Soft shell clams are yet another commercially harvested shellfish and are mainly utilized as cooked shellfish products.

Whelk is emerging as an important shellfish species in Rhode Island. Even though whelks are gastropods, they are marketed for their shucked meat. The similarity of the market makes whelk an ideal product to compete with other bivalve shellfish products in the market. Thus, we also include whelk in our study to see the impact of whelk harvested quantity on its own price and price of other related products.

Two other important shellfish commercially available in Rhode Island are eastern oyster and blue mussel. Even though they are harvested from open waters in small quantities, the majority of the production of these species is attributed to aquaculture operations. Oysters are mainly consumed as raw half-shell product whereas mussels are consumed as cooked products. The major share of the raw-half shell products all over United States consisted of oysters. The demand for mussels is also steadily increasing in US in recent years.

Regulation for Shellfish Industry

Apart from the different effort control strategies such as quantity and size limits the RI DEM adopts, every year RI DEM will issue permitting status for each of the shellfish harvest area. DEM and its appointed agents are responsible for growing and harvesting of shellfish and regulating the shellfish harvest areas. To initiate and manage the shellfish, Rhode Island Department of Environment and Management (DEM) have categorized the shellfish harvest area into different shellfish harvest areas. Following the guidelines instructed by National Shellfish Sanitation Program (NSSP) of USDA, the Office of Water Resources within DEM, conducts regular bacteriological and water quality sampling from the different harvest areas. Based on the routine bacteriological monitoring, the Office of Water Resources designates each of the harvest areas as Approved areas, Conditionally Approved/Prohibited Areas, and Prohibited Areas. Fishermen are permitted to harvest shellfish from approved harvest areas anytime of the year but they are forbidden to harvest permanently from prohibited areas unless DEM issue an approved notice for harvest.

Areas with conditionally approved/prohibited status permit the fishermen to harvest based on the quality of the water. The runoffs from the neighboring land to these areas would cause pollution to the water and therefore conditional closures usually occur after a heavy rainfall. Moreover, some of the areas are seasonally closed for harvest operations based on the historically high bacterial content during a particular period of a year. Unfortunately, the most productive area, Greenwich Bay is designated as conditionally approved area. Recently, based on the historically high bacterial content in the water during the third week of December to First week of January DEM announced a yearly seasonal closure for Greenwich Bay.

The intermittent closure of some of the harvest areas would hinder the supply flow of shellfish to the market. The fishermen cannot provide sufficient quantity of shellfish to the market when the harvest areas are closed while the market will be flooded with shellfish when the harvest areas are opened, especially on opening day. The revenue of the fishermen would be affected either by losing the supply of shellfish to market in event of closure or by losing the price due to overwhelming harvested shellfish in the market after opening. Moreover, the recent introduction of seasonal closure in Greenwich Bay would affect the revenue for the fishermen, as the timing of closure coincides with the festive events such as Christmas and New Year. The dealers who foresee the inconsistency in product flow would rely on shellfish, especially quahog from other states. Due to the aquaculture operations for quahogs in other states such as Virginia, the dealers could get consistent supply of quahog to the RI market which may bring down the ex-vessel price of quahog harvested in Rhode Island. In short, the current management strategy of closure of harvest area might have a negative influence on fishermen revenue.

This raised some important policy questions which need to be answered for the efficient functioning of shellfish management. The most important question is whether the price of shellfish will be dropped drastically if fishermen flood the market with products. Does the closure during the festive season have any effect on the price of quahog? Does the price of quahog from other states have an influence on the market price of quahog harvested in Rhode Island? A thorough understanding of shellfish markets is critically necessary for answering such questions. Currently, DEM, combined with Coastal Resource Management Council (CRMC) and Rhode Island Sea Grant, is working towards framing a new shellfish management plan for the state. In the wake of framing a new management policy framing, it is critically essential to answer the above mentioned policy questions.

1.3 Theoretical Model

Inverse demand systems are widely used in economic studies to analyze the demand of fish and seafood (Barten and Bettendorf 1989; Burton 1992; Eales, Durham, and Wessells 1997; Holt and Bishop 2002; Park, Thurman, and Easley 2004; Y. Lee and Kennedy 2008; Dedah, Keithly, and Kazmierczak 2011; M.-Y. A. Lee and Thunberg 2013). The inverse demand systems can be derived using specification of distance functions (Eales and Unnevehr 1991; Brown, Lee, and Seale Jr 1995).

Inverse demand systems are mainly used to analyze demand of perishable goods such as fruits and vegetables, meat products, and seafood. The supply of perishable products is very inelastic in the short term and therefore fishermen/producers are price takers (Barten and Bettendorf 1989). In such case, the price of good is affected by quantity and it is reasonable to assume that the normalized price with respect to income is a function of quantity of the good available and total real expenditure of all goods considered (Barten and Bettendorf 1989; Burton 1992) as defined in inverse demand system. Moreover, looking at the policy perspective, usually the fisheries management authorities are interested in understanding the effect of quantity harvested on price since they are interested in setting policy standards for the quantity harvested (M.-Y. A. Lee and Thunberg 2013).

In this study we used the Inverse Almost Ideal Demand System (IAIDS) model developed by Eales and Unnevehr (1991), which derives demand from distance function[2] a dual to the expenditure function. The function is assumed to have a linear-

[2] Deaton (1979) and Deaton and Muellbauer (1980b) describes the use of distance function in demand analysis. The function characterizes the distance from origin that the quantities must be consumed to

homogenous, concave, non-decreasing in quantities, and decreasing in utility similar to the properties explained for cost function in AIDS model.

The general form of IAIDS can be written as Eales and Unnevehr (1991):

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln q_j + \beta_i \ln Q, \tag{1}$$

where w_i is the value share[3] of good i, q_j is the quantity of good j, Q is the quantity index,[4] and α, β, and γ are parameters. The quantity index, $ln\ Q$ derived by Eales and Unnevehr (1991) is as follows:

$$\ln Q = \alpha_0 + \sum \alpha_j \ln q_j + 0.5 \sum_i \sum_j \gamma_{ij} \ln q_i \ln q_j \tag{2}$$

Due to the non-linear nature of the quantity index, most researchers use a linear approximation of this quantity index in their study for the ease of computation (Moschini 1995). Stone's Quantity index is a widely used quantity index similar to the original suggestion of Deaton and Muellbauer (1980a). The Stone's quantity index can be written as:

$$\ln Q = \sum_j w_j \ \ln q_j, \tag{3}$$

substituting equation (3) into (1), and noting that our data is a time series we add a t subscript to the resulting equation

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attain a particular indifference curve. Refer Deaton (1979) and Eales and Unnevehr (1991) for further details.

[3] Value share of a product is the ratio of its value to the total value of product in consideration which can be written as $\text{Value share } (w_i) = \frac{Value_i}{\sum_j Value_j}$,

[4] Quantity index does not have a meaningful interpretation; it exists merely due to mathematical derivation of equation (1). For details refer to (Eales and Unnevehr 1991).

$$w_{it} = \alpha_{it} + \sum_j \gamma_{ij} \ln q_{jt} + \beta_i \sum_j w_j \ln q_j, \quad (4)$$

The intention of the demand model was to measure the relationship between the price and quantity of good, but not just to find out how the budget share of a good is influenced by different factors. We can estimate the relationship by taking the marginal derivative of the budget share with respect to either quantity or price depending on the type of demand model we used. In direct demand models such as AIDS, price elasticity would be estimated to measure such relationships. However, in inverse demand systems price flexibility[5] will be calculated to analyze the effect of quantity harvested on price of the good. Price flexibility can be derived from the estimated parameters of IAIDS model by taking derivative of the share equation with respect to the log of quantity. We can write the equation as follows:

$$\partial w_i / \partial \ln q_j = \gamma_{ij} + \beta_i \left(\partial \ln Q / \partial \ln q_j \right), \quad (5)$$

which can be rewritten as:

$$\partial w_i / \partial \ln q_j = \gamma_{ij} + \beta_i \left(\alpha_j + \sum_k \gamma_{kj} \ln q_j \right) \quad (6)$$

But, from equation (4), $\alpha_j + \sum_k \gamma_{kj} \ln q_j = w_j - \beta_j \ln Q$

Therefore equation (6) can be rewritten as:

$$\partial w_i / \partial \ln q_j = \gamma_{ij} + \beta_i (w_j - \beta_j \ln Q) \quad (7)$$

[5] While mathematically price flexibility is an inverse of price elasticity, previous studies have shown that price flexibility is best estimated using the proper demand model that does not require computing price elasticity as an intermediate step (Huang 2005).

However, the derivation of the right hand side will yield,

$$\partial w_i / \partial \ln q_j = \varphi_{ij} w_i \tag{8}$$

Thus, after adjusting the terms on either sides, we can write own-price flexibility of good *i*, denoted as φ_i, as

$$\varphi_i = -1 + \frac{\gamma_{ii} + \beta_i \left(w_i - \beta_i \ln Q \right)}{w_i} \tag{9}$$

and cross-price flexibility between goods *i* and *j*, denoted φ_{ij}, as

$$\varphi_{ij} = \frac{\gamma_{ij} + \beta_i \left(w_j - \beta_j \ln Q \right)}{w_i} \tag{10}$$

A scale flexibility can be estimated using the homogeneity aggregation relation (Eales and Unnevehr 1991).

$$f_i = -1 + \frac{\beta_i}{w_i} \tag{11}$$

The price flexibility is interpreted similar as that of price elasticity. A good is price inflexible if the absolute value of own-price flexibility (equation 9) is less than 1. This means that the price changes less than proportionally to the unit change in quantity. The sign of cross-price flexibility will determine the substitutability and complementarities of two goods. If the cross-price flexibility is negative, then the two products in comparison are substitutes and if the measure is positive, then the products is complement to each other. Scale flexibility explains the change in price resulting from the expansion of total expenditure. Thus, if the scale flexibility is less than -1, the good is considered as necessary goods and if greater than -1, the good is considered as luxury goods (Park and Thurman 1999).

1.4 Data

Source

We obtained dealer-reported trip-level landings of shellfish in Rhode Island from the Statistical Atlantic Fisheries Information System (SAFIS). The data consists of daily landings of all the wild shellfish species harvested from open waters of Rhode Island from January 2007 to January 2013. It reports the quantity harvested and value, along with the unit of quantity used for trade (e.g., bushels, pounds, count). A total of 77 dealers reported their shellfish sales to DEM during this time period, of which only 13 or so dealers were consistently trading sizeable volume, whereas some of the other dealers operated seasonally. The daily landings was then aggregated to weekly level to smooth out some of the daily variations in the data.

SAFIS data for wild harvested shellfish in Rhode Island include quahogs, scallops, oysters, mussels, soft shell clams, and whelk (Table 1). The data clearly shows that quahog and scallop are the two main wild shellfish being landed in Rhode Island by volume, constituting an average of 86% of the total shellfish harvest volume. Soft shell clams were significant, but their recent downward trend has been dramatic; in 2012 soft shell clams accounted for a mere 0.35% of total landing. The recent reduction in landing for soft shell clams was so significant that the inclusion of the species would reduce the number of observations to 525 compared to total observation of 1695. Oyster and mussel landings are also small, but this is to be expected since

SAFIS data only reflects wild harvest, while the majority of products of these species being marketed originate from aquaculture. We disregarded oyster and mussel from the study, but their estimates might be significantly affected since oysters are the major competitor for the half-shell quahog market. Whelk is not a major species in volume, but is relatively consistent across years in our sample. Based on these observations, the species/products included in this study were quahog (by market categories), sea scallop, and whelk. The ex-vessel price of the species considered in this study were estimated from the landings data using the value and quantity landed. The data showed that neck quahogs have an ex-vessel price of $ 0.98/lbs, whereas the ex-vessel price of cherrystones and chowders were $ 0.40/lbs and $ 0.28/llbs respectively. The ex-vessel price of scallops was $ 1.03/lbs and the ex-vessel price of whelk was $ 1.18/lbs.

Market categories

The different consumption and market for each category of quahog encouraged us to consider them as different shellfish product. We inquired with experts in commercial quahog harvesting to determine the sensible market categories to include in this study. Of the four commonly cited market categories of quahog—littleneck, topneck, cherrystone, and chowder—we decided to combine the littleneck and topneck into one market category called necks (table 1). One of the main reasons for the decision was that the distinction of these two categories is not precise and hence the onsite sorting is said to be performed loosely. Thus, numbers recorded in SAFIS for littlenecks and topnecks may be quite inconsistent across different dealers. In addition, they both share same market- raw half-shell product. Cherrystone and chowder have distinct markets: former is mostly consumed as cooked product, and the latter is mainly used to make chowders as its name suggests. Thus, the study considered three categories of quahog namely, necks, cherrystone, and chowders.

Measurement unit conversion and price calculation

SAFIS records the landing volume by various units, which differ across products and dealers. For example, quahogs were mainly traded on either as per-pound or per-count; and sea scallops were traded by either as per-pound or per-meat-pound. We used the unit conversion table provided by DEM (Table 1.2) to align all volume units to pounds.

1.5 Empirical Model

The value share was regressed against landing quantities of own products and closely related products and quantity index. We also added other covariates to control for factors that would affect the expenditure share (w_{it}). First, given that the shellfish demand will vary across different months and particular festive season, we included dummy variables for months ($Month_m$) and week of Thanksgiving and Christmas ($Event_e$). Lastly, we included lagged quantity landed variable ($q_{j,t-1}$) to incorporate any inertia in the market that might carry over from previous market transaction.

Until recently, most researchers use approximation of the quantity index for the model estimation. The use of other quantity indices has been argued by some of the literature as it may cause biased parameter estimation (Moschini 1995). With the innovation in information technology and computation, it is now possible to estimate a model with non-linear component. Recent studies have used a non-linear (NL) model in AIDS (Chidmi, Hanson, and Nguyen 2012); in IAIDS (Thong 2012) to estimate demand system.

A comparison of estimates from both non-linear and linear model is necessary to check the approximation bias in the estimates. In this study we will estimate the value share for each equations in the system using both linear and a non-linear IAIDS models. The Akaike Information Criteria (AIC) value was used to compare the fit of the two models. Moreover, a t-test was also conducted to check any significant differences between the estimate and the variance.

The AIC value is used to select models from a set of models based on information theory. Kullback-Leibler distance, the distance between the model and the true value will be calculated. The criterion represents the model complexity by penalizing the degree of parameterization from the likelihood function. It measures the divergence of the probability model and the true sampling distribution and the model with lesser divergence, the model represents the distribution of the population. It is defined as:

$$AIC = -2(\ln(likelihood)) + 2k, \tag{12}$$

where k is number of parameters used in the model. Burnham and Anderson (2002) recommended computing AIC differences to compare the goodness of fit of two models. The AIC difference is defined as:

$$\Delta_i = AIC_i - AIC_{min}, \tag{13}$$

where AIC_{min} is the model with smallest AIC value and AIC_i is the AIC value of the alternative model. The model with $\Delta_i > 10$ can be omitted from further consideration since those models will not explain some of the substantial variation in the data.

This study aims to minimize the gap in the demand model study literature in two ways. First, we are estimating the two different versions of demand system model: *i)* Non-Linear IAIDS with original quantity index as defined in equation (2) and *ii)* conventional IAIDS with the approximation of quantity index defined in equation (3). We are analyzing the demand system of shellfish using NL-IAIDS where the original mathematical equation derived is used as quantity index. In addition, we are comparing the estimates from NL- IAIDS with the conventional IAIDS to analyze any significant differences between the estimates from the two different versions of quantity index. None of the literature which used the non-linear model has attempted to compare the original non-linear model with linear approximated demand model. Second, Deaton and Muellbauer (1980a) in their study have suggested to include any dynamic factors that might affect the quantity harvested. Recent studies which used NL models did not control dynamic factors such as season, lagged quantity in their model. We include the dynamic factors such as months, seasonal events to the model to control for such effects.

Thus, we can write our two versions of full model as:

i) NL-IAIDS with Original Quantity Index defined as in equation (2):

$$w_{it} = \alpha_{it} + \sum_{j=1}^{5} \gamma_{ij} ln\, q_{jt} + \beta_i \ln Q + \sum_{m=2}^{12} \mu_{im} Month_m + \sum_{\epsilon=TG}^{Xmas} \upsilon_{i\epsilon} Event_\epsilon$$

$$+$$

$$\sum_{j=1}^{5} \nu_{ij} \ln q_{j\, t-1} + \varepsilon_{it} \qquad (14)$$

ii) Traditional IAIDS With approximation for quantity index as defined in equation (3):

$$w_{it} = \alpha_{it} + \sum_{j=1}^{5} \gamma_{ij} \ln q_{it} + \beta_i \sum_{j=1}^{5} w_j \ln q_j + \sum_{m=2}^{12} \mu_{im}\, Month_m$$
$$+ \sum_{e=TG}^{Xmas} \upsilon_{ie}\, Event_e + \sum_{j=1}^{5} \ln q_{j,t-1} + \varepsilon_{it} \qquad (15)$$

Note that for the month dummy variable, January is set as the base month and is excluded from the estimated model to avoid collinearity with the constant term (α). For (14) and (15) to be consistent with the demand theory[6] and that the sum of value shares must equal to 1, following restrictions are imposed on the parameters during the estimation:

Homogeneity: $\sum_{j=1}^{5} \gamma_{ij} = 0$; Symmetry: $\gamma_{ij} = \gamma_{ji}$;

[6] These are (a) homogeneous of degree zero in prices and total expenditures taken together, and (b) Slutsky symmetry (Deaton and Muellbauer 1980a)

Summation: $\sum_{i=1}^{5}\alpha_i = 1, \sum_{i=1}^{5}\gamma_{ij} = 0, \sum_{i=1}^{5}\beta_i = 0, \sum_{i=2}^{5}\mu_{im} = 0,$
$\sum_{i=1}^{5}\upsilon_{ie} = 0, \sum_{i=1}^{5}\rho_{is} = 0, \sum_{i=1}^{5}\nu_{ij} = 0.$

Each product has its own regression equation, thus with five products (i.e., necks, cherrystone, chowder, scallop, whelk) we have five equations to estimate. Since we expect these five products/equations to influence each other in certain ways, we used an estimation method called Seemingly Unrelated Regressions (SUR) which gives consistent and asymptotically efficient parameter estimates (Deaton and Muellbauer 1980b) using the *sureg* command in STATA13 ®. For estimating the non-linear version of IAIDS model, we used a user-written command for non-linear SUR procedure (*nlsur*) with iteration in STATA13 ® to estimate the non-linear model.

Estimation Issues

Serial correlation of the disturbance term is a usual estimation issue in a time-series data analysis. Of the five equations for each of the shellfish used in the study, we will drop one of the equations out of the system to avoid a singular covariance matrix problem resulting from the adding up restriction we implied. Deaton and Muellbauer (1980b) explain that if the disturbances are not serially correlated, the maximum likelihood estimates from the model will be invariant to the deleted equation. If the disturbances are serially correlated, the maximum likelihood estimates will not be invariant to the deleted equation which will result in biased estimates.

The residuals from the model was used to identify the order of serial correlation present in the data. After estimating the model, the residuals were predicted. The predicted residuals were used to plot autocorrelation function and partial autocorrelation function and were represented as Figure 1.2a and 1.2b. The partial autocorrelation plot clearly shows that there is a presence of third order autocorrelation. One of the possibilities to tackle the autocorrelation is to re-specify the regressors. Berndt and Savin (1975) in their paper suggests a procedure to correct for first autocorrelation (AR (1)) process by adding the error term from the last period to the equation. Extending the procedure for AR (3) process, we can write the disturbances as:

$$u_t^n = \bar{R}^{n1}u_{t-1} + \bar{R}^{n2}u_{t-2} + \bar{R}^{n3}u_{t-3} + e_t^n, \qquad t = 1,2, \ldots., T, \tag{16}$$

where u_t^n is the vector of random error terms with mean zero, $\bar{R}^{ni}$ is the autocorrelation matrix and e_t^n is error vector normally distributed with mean =0 and covariance= Ω.

Adding equation (15) to the model, we will get an autocorrelation corrected regression model where $\bar{R}^n$ is included as a single-parameter specification.

$$S_t^n = f^n(x_t, \theta) + \bar{R}^{n1}u_{t-1} + \bar{R}^{n2}u_{t-2} + \bar{R}^{n3}u_{t-3} + e_t^n, \qquad t = 1,2 \ldots, T, \tag{17}$$

where S_t^n is vector of the shares of goods at time t, x_t is a vector of explanatory variables, θ is a vector of unknown parameters.

We ran the model after re-specifying the regressors and plot for autocorrelation and partial autocorrelation of the residuals were created. The autocorrelation and partial autocorrelation plots of the residuals predicted from the autocorrelation-adjusted dataset is represented in figure 1.3a and 1.3b respectively. Analyzing the plots show that there is no autocorrelation existing in the adjusted dataset. Moreover, we did a Cumby-Huizinga test for autocorrelation and the result of the test is represented in table 1.3. The result indicated that there is no issue of serial correlation in the dataset.

A Dickey-Fuller test was performed to each of the time series variables in the model to test whether the data is generated by stationary process. The null hypothesis for the test was that the time series contains unit root and the alternate hypothesis was that the time series data was generated by stationary process. The test showed each of the time series variables- value shares (w_i), log of quantity variables (lnq_i), lag of quantity (Lq_i), and quantity index (Q) reject the null hypothesis and concluded that they are all generated by stationary processes.

The explanatory variables were tested for presence of multicollinearity using the Variance Inflation Factor (VIF) test. An individual VIF of greater than 10 and average VIF greater than 6 is considered as an indication of severe multicollinearity. Our analysis showed that individual VIF for the variables ranged from 1.26 to 4.59 and average VIF was 3.09. Therefore, we can conclude that there is no problem of multicollinearity in the explanatory variables selected for the study.

The significance of the theoretical restrictions implied to the model was tested using a log-likelihood ratio (LR) test. We compared the restricted model with two cases of less restricted and an unrestricted model: i) model with no homogeneity restriction ii) model with no symmetry restriction, and iii) model with no homogeneity and symmetry restriction. The test rejects the null hypothesis and showed the significance of imposing restrictions. This suggests that the empirical results are theoretically consistent and valid for this functional specification.

1.6 Results

NL-IAIDS vs. Traditional IAIDS

The comparison of the two models were carried by analyzing the AIC values and t-test for the differences of estimates and standard errors. The AIC values of the two models were compared first to determine which model has better fit. The AIC for non-Linear model was -5260.32 and the AIC for linear conventional IAIDS model was -5337.48 indicating that the latter model has better bit. The difference of AIC values of the two models was 2.72, which indicates that the model with lower AIC (linear IAIDS model) would explain the model better compared to the other model.

The t-test of the difference between the estimates of two versions of the model NL-IAIDS and traditional IAIDS revealed that there is no statistical significance between the models. The t-values for the different shellfish product were 0.43 for neck quahog, 0.71 for cherrystone, 0.68 for chowders, 0.21 for scallops, and 0.68 for whelks were compared with the critical value of 1.684. Since the estimated t-statistic was lower than the critical value of t distribution, there is not enough statistical evidence to prove significant differences between the estimates and variance produced from the linear approximation of the quantity index and the original quantity index. Even though the goodness of fit of linear model is lower, the estimates and standard errors obtained from the two models are not significantly different. It is can be concluded based on the results of this study that there is no evident approximation bias from the quantity index used in the linear IAIDS.

Since the non-linear version is using the original quantity index and insignificant difference between the estimates from the two models, we are reporting the results from model with original quantity index (equation (14). The results obtained from approximated linear IAIDS model are represented in Appendix (Table A1).

Regression results

We tested for several alternative model specifications around equation (14). One aspect was whether to include the *Event* dummy variables for Thanksgiving and Christmas, since we already had November and December month dummy variables. AIC value was used to determine the goodness of fit of the model. The model with *Event* dummy had lower AIC value and following the standard procedure, we decided to keep the *Event* dummy variables as they added sufficient explanatory power. Thus, we will report the regression result of the model that contains dummy variables for seasonal events.

The regression results are presented in Table 1.4. The high adjusted R^2 value indicates that in general the model used for analysis appears to quite fit well. The explanatory power of all equation is high which ranges from 0.73 to 0.92. Our regression results show that value share of good i will increase when the quantity of that good increases, and the share will decrease when the quantity of other goods increase. This means, for example, that the value share of necks rises when the volume of necks increases, while the value share of necks decreases when the volume of chowder increases. We also found some seasonal variability patterns captured by month and event dummy variables. Different shellfish species have shown different seasonality patterns. We saw an increase in shares for the months of May through September compared to January's share for necks. The share of scallops was found decreasing in most of the months compared to January's share. However, share of whelk was shown to be increased during summer months and fall months such as October, November compared to January's share. The result did not show any significant effect of holiday events in the share of shellfish except for chowders.

Price flexibility estimates

The uncompensated own-price flexibility, cross flexibility, and scale flexibility are presented in Table 1.5. Regardless of the model, all flexibilities were estimated at the sample mean and all of them were statistically significant at 1 % level. The diagonal elements in bold in the table represents the own-price flexibility, while off-diagonal elements represent the cross-price flexibilities. The last column of the table represents the scale flexibility. Panel (a) is based on the regression model without Virginia prices, and panel (b) is from the model with Virginia prices. However, we will focus on the results presented in panel (b) for the reason mentioned above.

Own price flexibilities estimated are negative as expected and all are below -1 implying that all the shellfish species are price inflexible. In other words, the decrease in the price of these shellfish is less than proportional to the increase in landing volume. For example, for cherrystone a 1% increase in landed volume will decrease its price by 0.34%. The result indicates that sufficiently large change in quantity is needed to cause the price to change. This is consistent with the anecdotes we heard from the industry that the price of quahog usually varies within a relatively narrow range. It is however true that even with a small change in price per percentage-wise, the overall impact can still be significant if the change in quantity is large enough.

Cross-price flexibility, which measures the percentage change in price of good *i* due to 1% change in the quantity of another good *j*, shows whether two goods are substitutes or complements to each other. Negative cross-price flexibility indicates that the goods are substitutes, and positive cross-price flexibility indicates that the goods are complements (Houck 1965). Our results show that all products—not just necks and chowder—are substitutes to each other, which is not necessarily obvious because from dealers' point of view, the two products (say necks and chowder) can either be substitutes or complements. These relations could arise either from consumer demand (i.e., substitute products) or through complementarities in processing or distribution through the supply chain by the dealers (Scheld, Anderson, and Uchida 2012). It is difficult to know *a priori* which relation is dominant. Moreover, the intensity of the relationship differs with products because the range of the cross flexibility estimates differs. Cherrystone has the least substitutive relation with other shellfish which has lower negative cross-price flexibility values, closer to zero. Necks on the other extreme, with higher negative cross-price flexibility values indicate that they have stronger substitutive relation with other shellfish except Whelk.

Scale flexibility measures the change in price of a product with the expansion of consumption bundle (Park and Thurman 1999). The scale flexibility of all the shellfish products except whelk was closer to -1. This means that the consumption bundle of necks, cherrystone, chowders, and scallops are independent of the level of expenditure (Park and Thurman 1999). The necessary good status of shellfish in

Rhode Island might be indicating that the people of Rhode Island consider shellfish as one of the integral items of their diet.

1.7 Discussion and Conclusion

Several interesting results were found from our analysis. First, on average the prices of these shellfish products are inflexible, indicating that prices do not respond vigorously to small and moderate changes in quantity landed. Our result is supporting the result of Barten and Bettendorf (1989), which states that the price flexibility of perishable goods are inflexible for short time period. The economic theory suggests that fisherman will sell the products to the dealer and keep selling the products even when the quantities are large which keeps the price inflexible. However, if they realize that the quantity change is going to be permanent they will find alternative ways to sell the products which causes the price to be more flexible in the long term. This short-term price flexibility gave us an understanding that the unit price of shellfish will not change considerably with changes in quantity.

Our estimated price flexibility is not appropriate to predict the price change of a particular date, especially when there was a sudden and/or extremely large change in landings. For example, during one of landing days in December the volume landed for chowder increased from 214 pounds on one day to 3,055 pounds the next day accounting a 1,328% increase in volume. Based on the price flexibility measures estimated in this study (-0.95 for chowders), the price of chowders would decline by 1261%, but in reality, the price dropped from $0.40/lb to $0.31/lb, observing a decline of only 22.9%. Chowder volume came down soon after, indicating that observed sharp increase in volume was an incidental shock and not a permanent shift in trend. The variation in the price can be affected by so many factors including incidental and random noises (e.g., special events, weather conditions, dealer-specific incidents) that it is impossible to predict with any level of precision. This discrepancy might also point out an importance of omitting other shellfish products from the study. The omission of the oysters and soft shell clams which are strong competitors of raw half shell and cooked quahogs respectively might have an influence in the estimated price flexibility. Second, the shellfish products we considered in this study hold a substitutive relation with other shellfish products. This indicates that consumers' demand (i.e., substitutive relation) is dominant than potential complementarity of goods in processing or distribution through the supply chain.

There are a few caveats in our analysis stemming from lack of data that need to be mentioned. Our analysis did not include farmed oysters, mussels, and soft shell clams despite their dominant presence in shellfish market both statewide and nationally. Moreover, these shellfish compete with the products analyzed in this study. The production of oysters and mussels is mainly attributed to aquaculture. Currently, the data reporting in the farming sector is voluntary and therefore a very small portion of farmers are reporting their harvest. Moreover, we neither had sufficient resources nor time to collect enough data from aquaculturists.

We knew from interviewing industry experts that quantity traded and prices in neighboring states' markets could influence the Rhode Island market. It is for this reason that we intended to include quahog quantities marketed in Rhode Island from other states in our regression. Unfortunately, we could not get the market data of quahog from other states sold in RI market. Once we have the quantity data for those quahog products, we can include them as different shellfish products and analyze the price sensitivity. Since we suspect that the price of quahog from other states would influence the price of quahog harvested from Rhode Island, it is critically important to include those products to the system of products considered.

This study was the first in kind in Rhode Island to understand the price relationships with respect to the variation in quantity harvested in the short term. However, a long-term effect of the price change in response to the quantity harvested is warranted to get a comprehensive knowledge about the shellfish market. The short and long-term price flexibility estimates of shellfish will help the regulators to come up with changes in management policy so that price variation can be controlled efficiently. With the issues we mentioned above, future research is warranted.

The issues with management of shellfish resources are not just confined to Rhode Island. All the maritime states having shellfish resources encounter such concerns while framing a management policy. These problems will be exacerbated in southern US since the frequency of shellfish bed closure will be more frequent due to the warmer climate. Thus, this study has national policy relevance because understanding the market of a natural resource in a state is critically important in framing an efficient and successful management policy.

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Table 1.1 Quantity landed for each shellfish species in Rhode Island

	Quantity (in 1,000s lbs)					
Species	2007	2008	2009	2010	2011	2012
Quahog	4,684	4,232	3,853	4,544	5,114	6,961
Necks	3,074	2,795	2,442	2,959	3,641	5,121
Cherrystones	161	208	187	201	188	268
Chowders	1,448	1,227	1222	1,387	1,283	1,571
Oyster	39	13	15	6	4	52
Mussel	0	0	682	626	205	0
Scallop	11,217	2,516	2,830	2,226	5,751	8,011
Soft Clam	1,292	708	490	698	183	41
Whelk	361	423	715	658	745	626
Total	17,592	7,890	8,583	8,761	12,000	15,690

Note: the sum of necks, cherrystones, and chowders do not match the top row for quahog due to rounding errors from unit conversions.

Table 1.2 Conversion factors used to convert Different yield units to pound

		Conversion Factor		
Species	Market category	Count to pound	Meat pound to Pound	Bushels to Pound
Quahog				
	Little Neck	7	6.53	N/A
	Top Neck	4.5	6.54	N/A
	Cherrystone	5.75	6.55	N/A
	Chowder	2.5	6.56	N/A
Oyster		0.53	7.5	39.675
Mussel		0.05	3.33	60
Bay Scallop		N/A	9.375	46.875
Sea Scallop		N/A	8.33	N/A

Note: For quahogs, the quantity harvested is reported in count, the quantity is divided by the number given in the first column. For example, if the daily reported quantity of top neck is 100 counts, the quantity in terms of pounds is calculated by dividing reported quantity 100 by 4.5 (100/4.5) which is equal to 22.22 lbs. For scallops where the harvest is reported in meat pounds or bushels, then the quantity is multiplied by the factor given. N/A indicates that the harvest quantity of a species is not reported in that unit.

Table 1.3 Cumby-Huizinga test for autocorrelation

HA: Serial Correlation present at lag specified

Lag	chi-Square	Degrees of freedom	p-value
1	0.24	1	0.63
2	0.56	1	0.45
3	1.46	1	0.23
4	0.00	1	0.99
5	0.99	1	0.32

Note: The residuals were predicted using the autocorrected data by re-specifying the regressors. The autocorrelation test was conducted to see if the lag of the residuals are correlated to each other.

Table 1.4 Parameter estimates from NL-IAIDS model for Shellfish in Rhode Island

	Necks	Cherrystone	Chowder	Scallop	Whelk
RI Quantity harvested					
Necks	0.20***	-0.01***	-0.03***	-0.16***	-0.001***
	(0.01)	(0.001)	(0.002)	(0.01)	(0.005)
Cherrystone	-0.01***	0.01***	0.001	-0.004***	-0.001***
	(0.001)	(0.001)	(0.001)	(0.0004)	(0.0004)
Chowder	-0.03***	0.001	0.05***	-0.02***	-0.0004
	(0.002)	(0.001)	(0.003)	(0.001)	(0.001)
Scallop	-0.16***	-0.004***	-0.02***	0.22***	-0.03***
	(0.01)	(0.0004)	(0.001)	(0.01)	(0.01)
Whelk	-0.001	-0.001***	-0.0004	-0.03***	0.03***
	(0.005)	(0.0004)	(0.001)	(0.01)	(0.01)
Quantity Index	-0.08***	-0.002***	-0.01***	0.10***	-0.01
	(0.004)	(0.0004)	(0.001)	(0.01)	(0.01)
Lagged Quantity					
Neck	-0.00002				
	(0.00001)				

Cherrystone		0.00005			
		(0.0002)			
Chowder			-0.0002		
			(0.0001)		
Scallop				-0.00001	
				(0.0001)	
Whelk					0.000003
					(0.00003)
Month dummy (base = January)					
February	-0.01	-0.001	-0.01	0.01	0.01
	(0.02)	(0.002)	(0.01)	(0.03)	(0.01)
March	0.02	-0.001	0.004	-0.06	0.03 *
	(0.03)	(0.002)	(0.01)	(0.04)	(0.02)
April	0.03	-0.0005	0.003	-0.06 **	0.03
	(0.03)	(0.002)	(0.01)	(0.03)	(0.02)
May	0.08 ***	0.002	0.004	-0.13 ***	0.05 **
	(0.03)	(0.002)	(0.01)	(0.03)	(0.02)
June	0.07 ***	-0.00004	0.001	-0.12 ***	0.05 **

	(0.02)	(0.002)	(0.01)	(0.03)	(0.02)
July	0.04***	-0.0005	-0.0004	-0.06**	0.02
	(0.02)	(0.001)	(0.004)	(0.0)	(0.02)
August	0.04*	-0.001	-0.001	-0.06**	0.02
	(0.03)	(0.001)	(0.005)	(0.03)	(0.02)
September	0.07***	0.00002	-0.001	-0.10***	0.03**
	(0.03)	(0.002)	(0.005)	(0.03)	(0.02)
October	-0.01	-0.001	-0.01	-0.10***	0.12***
	(0.03)	(0.002)	(0.005)	(0.03)	(0.03)
November	-0.02	-0.002	-0.01*	-0.09**	0.12***
	(0.04)	(0.002)	(0.01)	(0.04)	(0.03)
December	0.13***	0.001	0.01	-0.11***	-0.03
	(0.03)	(0.002)	(0.01)	(0.04)	(0.03)
Thanksgiving	-0.03	-0.001	-0.003	0.02	0.01
	(0.04)	(0.002)	(0.002)	(0.05)	(0.05)
Christmas	-0.11***	-0.003	-0.02	0.15***	-0.02
	(0.03)	(0.002)	(0.01)	(0.04)	(0.03)
Constant	.88***	0.04***	0.12***	-0.71***	0.67***

	(0.04)	(0.004)	(0.01)	(0.04)	(0.05)
Observations	288	288	288	288	288
R^2	0.92	0.81	0.84	0.87	0.73

Note: Each column represents determinants of share of expenditure of each shellfish species estimated simultaneously using non-linear Seemingly Unrelated Regression (SUR). The determinants of expenditure share include quantity harvested of its own species and quantity harvested of other related species in Rhode Island. In case of the quahog, expenditure share of quahog via, the price will also depend on price of these market categories in other states. Therefore, we also included price of market categories of quahog from other states to the model. Month dummy, thanksgiving & Christmas dummy were included in the model to capture any effect of season and festival in expenditure share. One-period lag of the quantity harvested were also included to capture the effect of the quantity harvested in previous time period on the current time period expenditure share. Standard errors are reported in parentheses. *, **, and *** represents statistical significance at the 10%, 5% and 1% levels respectively.

Table 1.5 Uncompensated price and scale flexibility of Shellfish in Rhode Island

	Quantity					Income
	Necks	Cherrystone	Chowders	Scallop	Whelk	
Necks	**-0.48**	-1.95	-1.59	-0.46	-0.11	-1.38
	(± 0.10)	(± 0.60)	(± 0.46)	(± 0.15)	(± 0.49)	(±0.08)
Cherrystone	-0.05	**-0.34**	-0.02	-0.01	-0.02	-1.33
	(± 0.02)	(± 0.56)	(± 0.49)	(± 0.01)	(± 0.03)	(±0.30)
Chowders	-0.18	-0.07	**-0.95**	-0.06	-0.02	-1.37
	(± 0.05)	(± 0.52)	(± 0.50)	(± 0.02)	(± 0.13)	(±0.18)
Scallop	-0.42	-0.42	-0.48	**-0.39**	-0.58	-1.13
	(± 0.07)	(± 0.15)	(± 0.12)	(± 0.19)	(± 0.28)	(±0.18)
Whelk	-0.03	-0.18	-0.06	-0.16	**-0.32**	-1.13
	(± 0.09)	(± 0.25)	(± 0.23)	(± 0.10)	(± 0.46)	(±0.54)

Note: Each column represents price flexibility of each species. All the price flexibility estimated are statistically significant at 0.01 levels. Standard deviation of the flexibility is given in parentheses. Adding and subtracting the standard deviation to the estimate will give us the confidence interval for each estimate. The numbers represented in bold represents the own-price flexibility and the other digit represents cross price flexibility between the corresponding shellfish species. The last row of the table represents scale flexibility. The flexibility was calculated using the coefficients of the quantity variables and quantity index variables in the Inverse Almost Ideal Demand System model.

Figure 2.1 Rhode Island Shellfish Harvest Areas

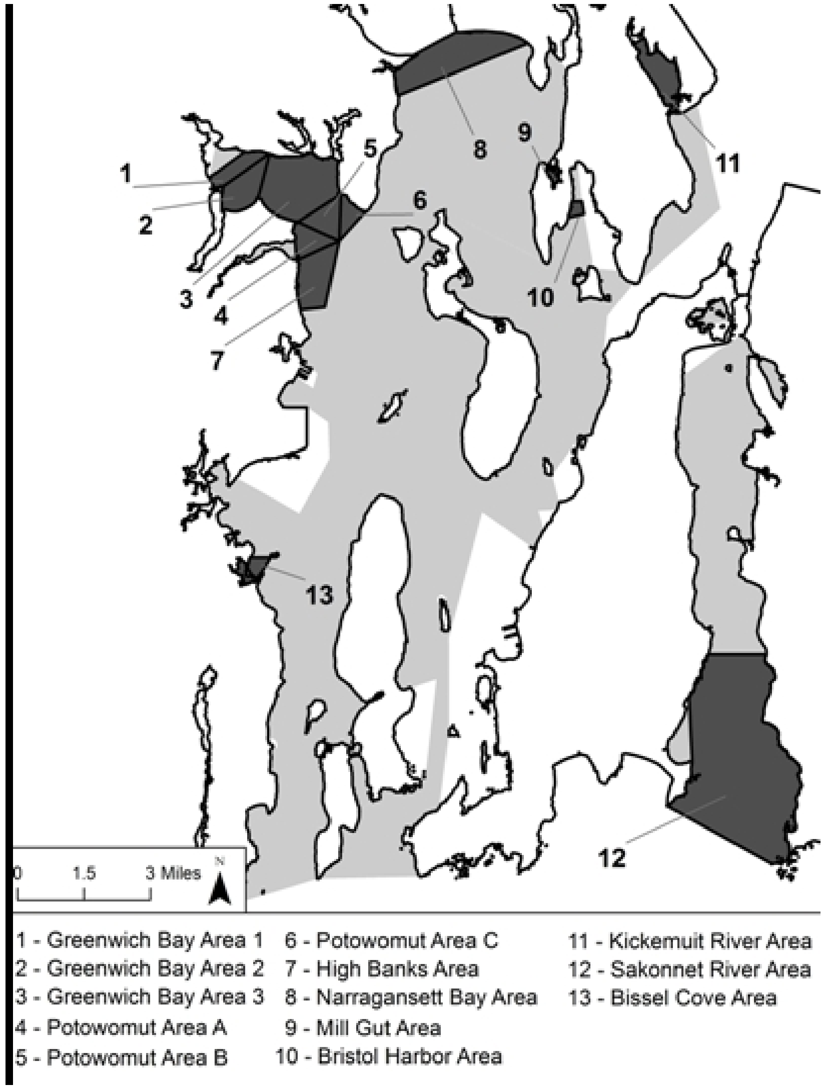
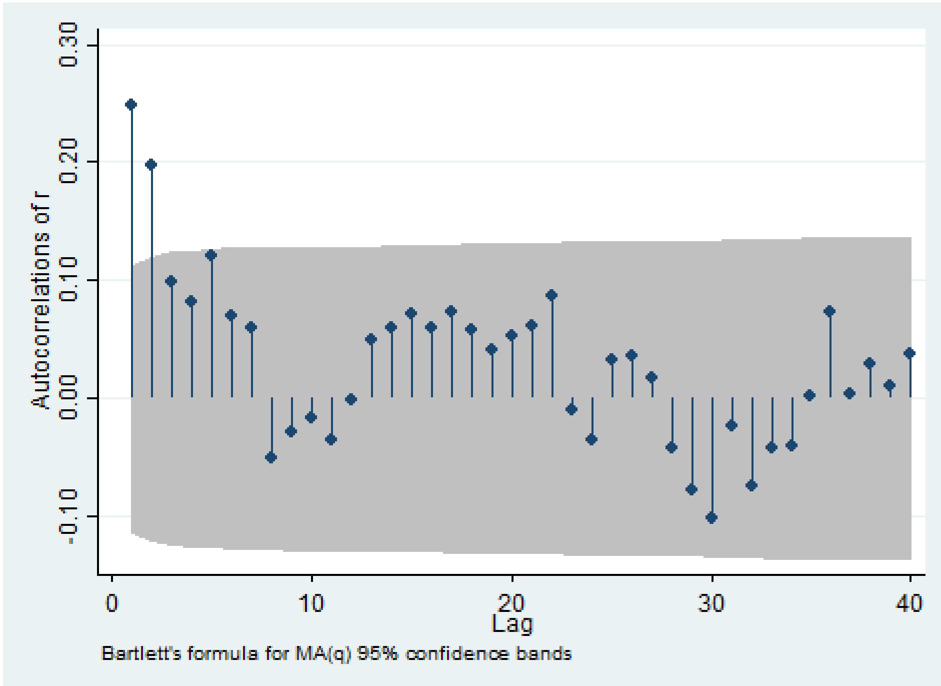
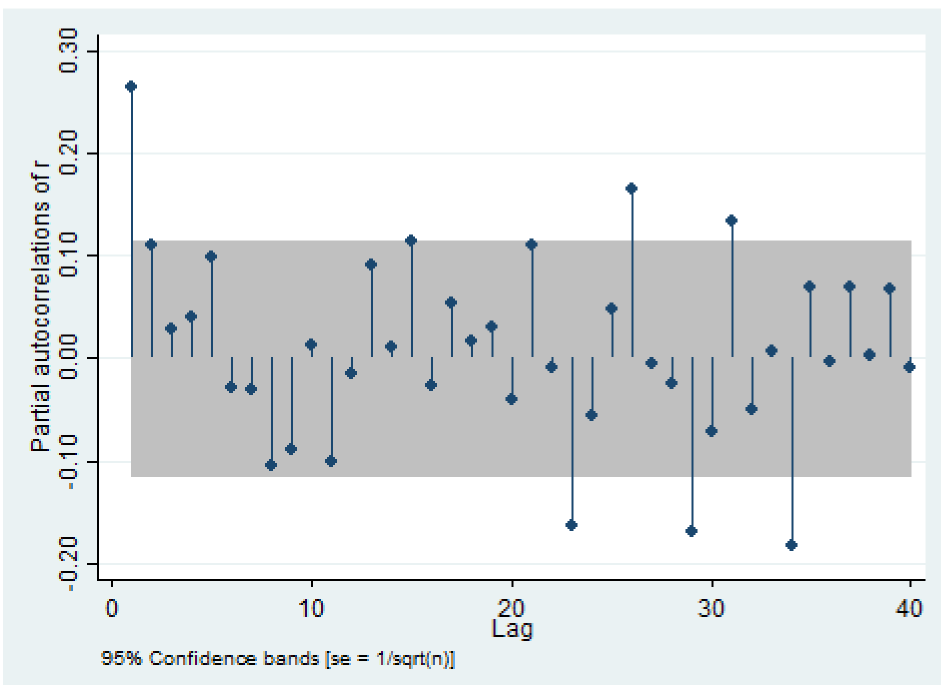


Figure 1.2 Autocorrelation and Partial autocorrelation function plot of the residuals

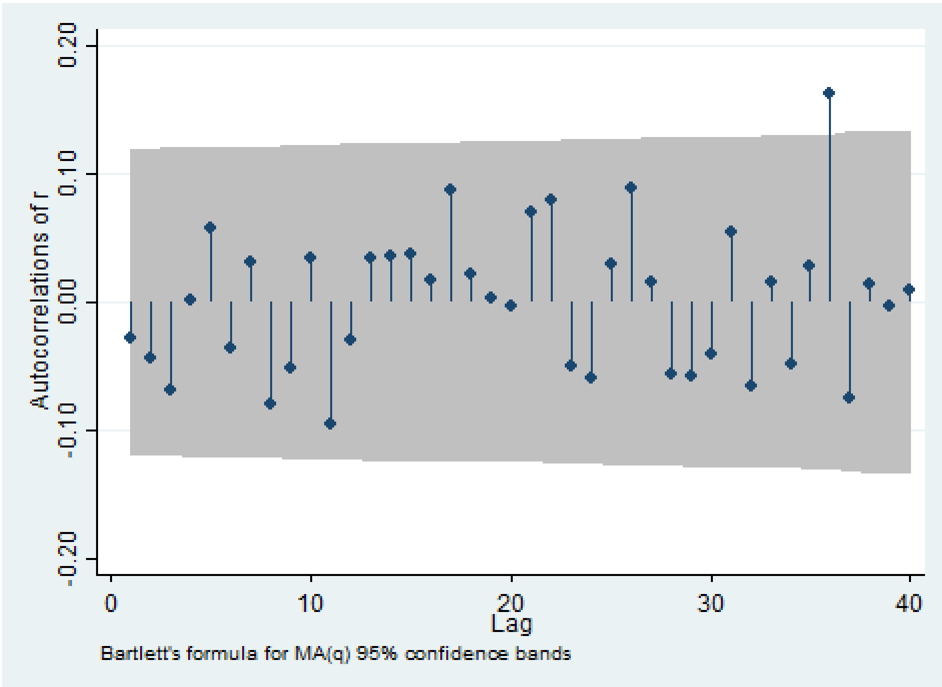


a) Autocorrelation function plot of residuals

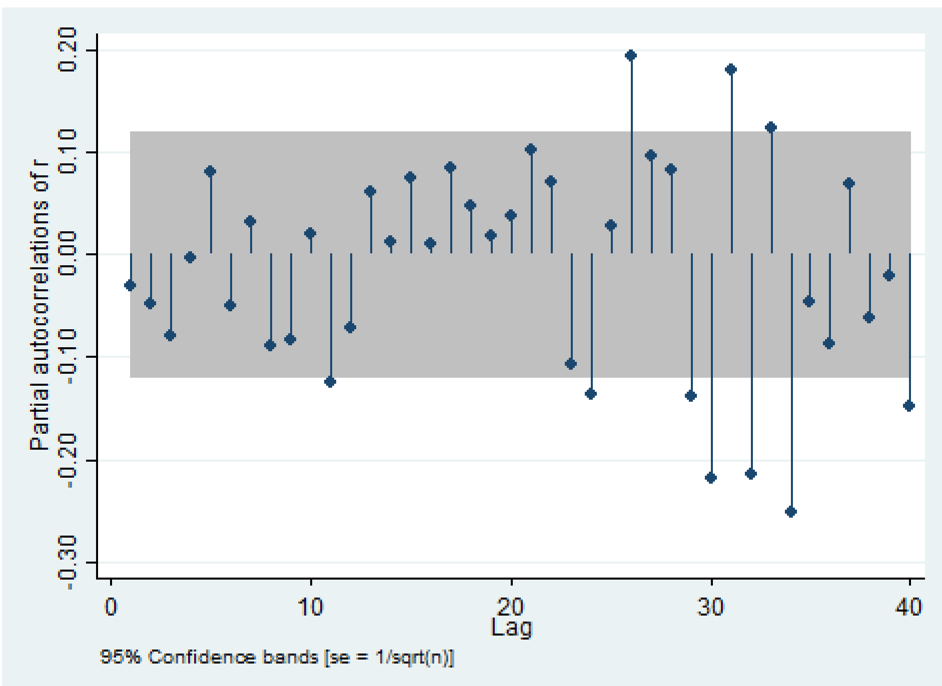


b) Partial autocorrelation function plot of residuals

Figure 1.3 Autocorrelation and Partial autocorrelation plots of the autocorrected residuals



a) Autocorrelation plot of the corrected residuals



b) Partial autocorrelation plot of autocorrected residuals

Appendix

Table 1.A Parameter estimates from Conventional IAIDS model for Shellfish in Rhode Island

	Necks	Cherrystone	Chowder	Scallop	Whelk
RI Quantity harvested					
Necks	0.13 ***	-0.01 ***	-0.03 ***	-0.08 ***	-0.01 ***
	(0.01)	(0.001)	(0.002)	(0.004)	(0.004)
Cherrystone	-0.01 ***	0.01 ***	-0.00002	-0.002 ***	-0.001 ***
	(0.001)	(0.001)	(0.001)	(0.0002)	(0.0003)
Chowder	-0.03 ***	-0.00002	0.04 ***	-0.01 ***	-0.003 ***
	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Scallop	-0.08 ***	-0.002 ***	-0.01 ***	0.10 ***	-0.01 ***
	(0.004)	(0.0002)	(0.0001)	(0.004)	(0.002)
Whelk	-0.01 ***	-0.001 ***	-0.003 ***	-0.01 ***	0.03 ***
	(0.004)	(0.0003)	(0.001)	(0.002)	(0.004)
Quantity Index	-0.06 ***	-0.001 ***	-0.01 ***	0.10 ***	-0.03 ***
	(0.01)	(0.0005)	(0.001)	(0.01)	(0.01)
Lagged Quantity					
Neck	0.000001				

	(0.000001)				
Cherrystone		0.00003			
		(0.00002)			
Chowder			-0.000001		
			(0.00001)		
Scallop				-0.00004	
				(0.00002)	
Whelk					0.00001
					(0.0002)
Month dummy (base = January)					
February	-0.01	-0.001	-0.01 *	0.02	0.001
	(0.03)	(0.001)	(0.004)	(0.03)	(0.02)
March	0.01	-0.001	0.001	-0.02	0.01
	(0.03)	(0.001)	(0.004)	(0.03)	(0.02)
April	-0.02	-0.001	-0.002	0.02	-0.002
	(0.02)	(0.001)	(0.004)	(0.03)	(0.01)
May	0.002	0.001	-0.0001	0.02	-0.02

	(0.03)	(0.001)	(0.005)	(0.03)	(0.02)
June	0.03	-0.0001	0.001	-0.01	-0.02
	(0.03)	(0.002)	(0.00)	(0.03)	(0.02)
July	-0.02	-0.001	-0.004	0.03	-0.01
	(0.02)	(0.001)	(0.004)	(0.03)	(0.02)
August	0.01	-0.001	-0.002	-0.01	0.01
	(0.03)	(0.001)	(0.005)	(0.03)	(0.02)
September	-0.01	-0.001	-0.01	0.01	0.01
	(0.03)	(0.001)	(0.005)	(0.03)	(0.02)
October	-0.05	-0.001	-0.01 **	0.02	0.04 *
	(0.03)	(0.001)	(0.005)	(0.03)	(0.02)
November	-0.06 *	-0.002	-0.01 **	0.02	0.05 ***
	(0.03)	(0.002)	(0.005)	(0.04)	(0.02)
December	0.08 **	0.0001	0.01	-0.02	-0.07
	(0.03)	(0.001)	(0.005)	(0.04)	(0.02)
Thanksgiving	-0.01	-0.0001	-0.0002	0.004	0.004
	(0.04)	(0.002)	(0.01)	(0.004)	(0.02)
Christmas	-0.06	-0.003	-0.01 **	0.03	0.04

	(0.04)	(0.002)	(0.01)	(0.04)	(0.02)
Constant	0.42***	0.03***	0.10***	-0.32***	0.77***
	(0.05)	(0.002)	(0.01)	(0.05)	(0.03)
Observations	272	272	272	272	272
R^2	0.81	0.73	0.79	0.85	0.63

Note: Each column represents determinants of share of expenditure of each shellfish species estimated simultaneously using non-linear Seemingly Unrelated Regression (SUR). The determinants of expenditure share include quantity harvested of its own species and quantity harvested of other related species in Rhode Island. In case of the quahog, expenditure share of quahog via, the price will also depend on price of these market categories in other states. Therefore, we also included price of market categories of quahog from other states to the model. Month dummy, thanksgiving & Christmas dummy were included in the model to capture any effect of season and festival in expenditure share. One-period lag of the quantity harvested were also included to capture the effect of the quantity harvested in previous time period on the current time period expenditure share. Standard errors are reported in parentheses. *, **, and *** represents statistical significance at the 1%, 5% and 10% levels respectively.

MANUSCRIPT-2

Analysis of the Economic Performance of the Quahog Transplant Program in Rhode Island

To be submitted to *Marine Resource Economics*

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Abstract

Assessing the economic performance of any management strategy is essential for analyzing its success, especially stock replenishment programs. Since most of the replenishment programs are designed for local fisheries, the economic performance of these programs varies with location and fishery. Using Rhode Island as a case study, we consider the shellfish transplant program and measure its economic performance. The transplantation is carried out in Rhode Island by collecting marketable size quahogs from prohibited fishing areas and stocking them to selected open fishing areas. The direct benefit of transplantation is increased harvest of quahogs from the transplanted fishing areas. The economic benefits from the program cannot be estimated directly, since there is no tracking mechanism for transplanted quahogs. One way to assess the benefits of enhancement programs is to analyze their effects on the quantity of harvested quahogs. This study showed that the there is no statistical evidence to indicate that transplantation influences the harvest of quahogs from the Narragansett Bay area. However, the net returns indicate that the transplant program is profitable.

2.1 Introduction

Economic assessment of stock replenishing management[7] practice is essential for its effective implementation and achieving the ultimate goal of sustainable resource management. The success of management practices depends on two main components: achieving technical objectives; and achieving economic and social goals (Garcia and Charles 2007; Charles 2008). Analyzing the results of some previous studies investigating economic performance of stock replenishing programs revealed that they can either benefit or harm the resource economically. Certain studies showed that stock replenishing programs deliver economic and social benefits by creating new opportunities for fishing (Smith, Nguyen Khoa, and Lorenzen 2005; Garaway 2006), whereas others indicate evidence of no economic and social gains from the programs (Hilborn 1998; Levin, Zabel, and Williams 2001; Arnason 2001; Naish et al. 2007). The mixed response from the economic performance of these programs strongly supports the importance of economic analysis. Lorenzen, Leber, and Blankenship (2010) suggested that the performance of stock replenishing programs differs with location and depends on preexisting economic conditions. Thus, a proper assessment will help the managers to judge the success of the program in terms of biological, economical, and social gains. Organizations such as the Food and Agricultural Organization of the United Nations (FAO) and The Science Consortium for Ocean

[7] Stock replenishing programs are any human interventions intended to sustainably improve the productivity of a fishery resource. Even though these management strategies are widely known as stock enhancement programs, we use the term stock replenishing program to avoid confusion, since stock enhancement refers to only one management strategy.

Replenishment (SCORE) realize the importance of economic feasibility in the success of these stock enhancement programs.

One of the main drawbacks of stock replenishing programs is that many evaluation studies do not consider all of their economic effects. Caddy, Defeo, and Defeo (2003) recommend that the true economic evaluation of stock replenishing programs can be enumerated by considering all possible intertemporal flows of benefits and costs; yet one of the impeding factors in economic evaluation is the difficulty in estimating their total benefits and costs (Caddy, Defeo, and Defeo 2003).

Using a case study in Rhode Island, this study analyzes the benefits of the stock replenishment program for the shellfish fishery. The state mainly conducts this program in the form of stock transplants. Management authorities select some of the prohibited fishing areas to collect market-size quahogs[8] with the help of fishermen. The collected quahogs are then stocked in well-marked areas within some of the state's open fishing areas. The marked areas are closed to fishing for the following six months to allow the newly stocked quahogs to purge harmful bacteria through the process of natural depuration. Since its introduction, no formal scientific study has been conducted to estimate the effect of transplants on the stock population or feasibility of the program in Rhode Island.

Our ultimate aim of this study is to estimate the economic feasibility of transplant operations in Rhode Island. An economic feasibility study is used to demonstrate net benefits of a new program by considering the benefits and costs

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[8] Quahog, also called hard shell clam is an edible bivalve mollusk, native to the eastern side of Northern America.

involved. However, the economic benefits of the transplant program cannot be estimated directly, since there is no tracking mechanism in place. One way to evaluate the benefits of the stock replenishment program is to analyze its effect on the harvested quantity of quahogs. Specifically, we will analyze the effect of transplantation in the Narragansett Bay area on (1) the quantity of quahogs harvested in RI; and (2) its economic feasibility.

2.2 Background

In Rhode Island, the management of shellfish is carried out by the Rhode Island Department of Environmental Management (DEM) and its appointed agents, who are responsible for regulating the shellfish harvest areas, growing, and harvesting (SMP 2014). To initiate and manage the shellfish, DEM has categorized shellfish growing areas into six main fishing areas, which is further categorized into 21 shellfish harvest areas. The details of all shellfish areas are summarized in Table 2.1. One of the main management measures DEM adopts is public safety from consumption of shellfish. In order to prevent bacterially contaminated shellfish from reaching the market, DEM conducts annual bacteriological sampling from the different fishing areas. Based on the water quality, fishing areas are categorized as approved, prohibited, or conditionally closed. Fishermen are permitted to harvest shellfish from approved harvest areas year-round, but they are forbidden to harvest from prohibited areas unless DEM issues an approved notice for harvest. Areas with conditionally approved/prohibited status permit the fishermen to harvest based on the quality of the water after a weather event. In addition, some areas, such as Greenwich Bay and Block Island, are given special attention by declaring seasonal closures.

In addition to managing shellfish resources based on public safety issues, authorities consider management policies to conserve and replenish shellfish resources in the Bay[9]. One of the management strategies adopted by DEM for enhancing the quahog population is to create spawner sanctuaries. The selected harvest areas prohibit any kind of fishing activities. The sanctuary acts as a source for quahog recruitment and thereby helps to enhance the quahog population. Currently there are five spawner sanctuaries throughout the coastal waters of Rhode Island: one in Potowomut Management Area for the whole Bay area and four areas in each of the coastal ponds. The sanctuary site in the Narragansett Bay area was selected jointly by the DEM management office and fishermen. However, scientific studies of the effect of such sanctuaries on the quahog population have not been conducted (Dennis Erkan, DEM, personal communication).

As previously mentioned, another management practice implemented by DEM is enhancing quahog stocks by transplanting quahogs from prohibited areas. Even though the main goal of the transplant process is to help fishermen increase their winter harvest, the DEM also aims to increase the overall health of quahog populations in Bay area. Quahogs are collected from prohibited/closed harvest areas and transplanted to open shellfish harvest areas. After consulting with the Office of Water Resources regarding the bacterial status of the various locations, DEM selects the receiving quahog transplant site. Quahogs have been transplanted mainly to the Potowomut Management Area (Area 3) and Bristol Shellfish Transplant Area (Area

[9] The DEM also manages the shellfish resources in the state by fixing quantity and size limits of the catch.

4). These newly stocked transplant areas will be open to harvest after conditional closure for six months.[10] The operation usually takes place during June–July each year, and the restocked areas are opened to fishermen beginning in January of the following year. The authorities allow only participating fishermen to harvest from the transplanted area. Thus, the harvesting fishermen have full information about the newly stocked areas, helping them to harvest efficiently the following winter.

2.3 Data

Quantity of Quahogs Harvested

We obtained dealer-reported trip-level landings for quahogs in Rhode Island from the Statistical Atlantic Fisheries Information System (SAFIS). This detailed report consists of daily landings of wild quahogs harvested from the open waters of Rhode Island from January 2007 to January 2013. It reports the quantity harvested and value, along with the quantity unit used for trade (e.g., bushels, pounds, count). In addition, it also provides details about the shellfish harvest areas, fishing ports used, dealers to which the landings were sold, and types of fishing licenses. A total of 1,031 fishermen reported their landings from 6 fishing areas. There was a total of 77 dealers during this time period. The distribution of quahog fishermen in the different shellfish harvest areas are represented in Figure 2.1. It shows that fishermen harvest mostly in Area 3, followed by Areas 1, 4, and 2.

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[10] Since the quahogs were collected from prohibited shellfish harvest areas, the bacterial content in their body is too high to be safe for human consumption. The conditional closure of the newly stocked area will allow enough time for quahogs to reduce the bacteria to a human safe level through natural depuration processes.

Since the landings report obtained from DEM contain raw data, certain data cleaning was required before the analysis. First, SAFIS records the landings volume by various units, which differ across products and dealers. For example, quahogs were mainly traded on either a per-pound or per-count basis. We used the unit conversion table provided by DEM (Table 2.2) to standardize all volume units to pounds. Second, the data comprised the quantity of quahogs harvested from each shellfish harvest area, including the Narragansett Bay area, Block Island, and coastal ponds. Considering that the transplant program in Rhode Island is carried out only in Narragansett Bay, we did not consider the observations from coastal ponds and Block Island (Area 6). The final data used for our analysis consists of quahog quantity harvested from five main shellfish areas in the Narragansett Bay area.

A unique identifier was created by grouping fishermen and landing areas in order to maintain confidentiality. Moreover, some of the fishermen harvested in multiple fishing areas in a day. By creating an identifier that associated fishermen and fishing areas, we can categorize those harvests as two different events.

The data obtained from SAFIS are daily dealer reports of quahog landings. However, the effect of transplantation on daily harvested quantity is too small to capture. We aggregated the daily data to a quarterly level to account for this time scale.

Data on Quahog Transplants

Details about the quahog transplant program were collected from the DEM office. The monthly data (2003 to 2012) describes the quantity transplanted in pounds, quahog collection areas, and transplant receiving areas. It also describes the major fishing ports and details of the nearest transplant receiving areas. During this time period, transplants occurred in four shellfish harvest areas; namely, the High Banks Management Area, Potowomut Management Spawner Sanctuary, Bissel Cove/Fox Island Management Area, and Bristol Shellfish Transplant Management Area. The first three transplant sites belong to the main harvest area 3 and the fourth one belongs to main harvest area 4. The map showing the geographical location is represented in Figure 2.2. Since the newly stocked quahogs are available for harvest after six months have passed, we introduced the transplanted quantity to the main dataset as a lag of two time periods, since the main data are aggregated quarterly.

2.4 Model

The fundamental assumption maintained throughout this chapter is that if the transplant program has a positive influence on the stock population, this will be reflected as an increase in harvested quantity. The increased number of quahogs in the transplanted sites should increase the harvested quantity from those sites as well as possibly in other harvesting areas through spawning and larval dispersion. By including transplanted quantity in the model, along with other characteristics, such as factors influencing harvested quantity, we can differentiate the effect of the transplants on quantity harvested.

The quantity harvested from a fishing area at a particular time depends on the biological characteristics of the area, environmental characteristics, and the extent of fishing effort. The biological characteristics affect fish harvest through the productivity of that area, which, in turn, depends on the population density, new batch recruitments, and the mortality rate of the species in that area. However, information about population density, recruitment, and mortality rate is difficult to measure and is not available for Rhode Island shellfish resources. One of the factors that can be used as a proxy for productivity of the fishing area is total shellfish production in the previous time period. If the recruitment and mortality rate remains the same, the catch from the previous time period will give us information about stock population. Assuming that recruitment and mortality remained same during the study period, we used the cumulative catch of quahogs from the previous quarter as the biological characteristic affecting harvest.

The main environmental characteristics affecting harvest are weather and management area closures. A quarter fixed effect was used to capture such time variant effects of each fishing area.

The important fishing characteristics that affect the harvest of a particular fishing area are the frequency of fishing trips and effort concentration. The relationship between the number of fishing trips and quantity harvested is not linear. The harvest will increase with an increase in fishing trips, but it will decrease due to increased fishing pressure on the stock. Considering this, we assumed a quadratic relationship between harvest and number of trips. The effect of fishing effort will be different for different fishing sites based on the characteristics of the fishing sites such as the area of the site and the number of open fishing days for that quarter. If the area of a fishing site is small, the fishermen would need less effort to catch quahogs compared to fishing sites with larger areas. The fishermen can catch more quahogs if there are open fishing days for a fishing site in a quarter. The quadratic term of the number of trips is compounded by effort concentration of each fishing area. Effort concentration is defined as the number of fishing trips made by the fishermen to a fishing site divided by the area of that site and the number of open fishing days for the site in a quarter.

The factors that affect the quantity of quahog harvested from a particular fishing area *i* at time period t can be written as:

$$Q_{it} = \alpha_{it} + \beta_{it} T_{it-2} + \delta_{it} Q_{it-1} + \theta_{it} ntrips_{it} + \gamma_{it} \frac{ntrips_{it}^2}{(effort\ conc)} + \sum_{l=1}^{3} \mu_l Qtr_l + \epsilon_{it}, \quad (1)$$

where Q_{it} is the quantity of quahogs harvested from shellfish harvest area *i* at time *t*; T_{it-2} is the quantity of transplanted quahogs in harvest area *i* in a two-lag period; Q_{it-1} is the cumulative catch of quahogs from fishing area *i* in quarter *t-1*, which is the proxy for productivity of the fishing area; $ntrips_{it}$ is the number of fishing trips made by fishermen to fishing area *i* in quarter *t*; *effort conc* is the effort concentration, which depends on the area of the fishing site and number of open fishing days of fishing area *i* at quarter *t*; and ϵ_{itr} is the random error component. The two-lag period given to the transplanted quahog, *T*, was used to adjust for the effect of conditional closures of the transplanted areas for six months.

In order to understand whether the transplant program is economically feasible, we estimated the net benefits of the program as follows. Once the regression was run, we were able to predict the quantity harvested from the transplanted quantity. Using that predicted quantity of quahogs and the average market price, we calculated the total revenue fishermen received from transplantation of quahogs. The cost of the quahog transplant program consists mainly of fishing cost, including fuel and labor costs. Transplanting costs were obtained from DEM, and the total cost was subtracted from the total revenue to determine profit of the transplant operations. If the net return is positive, this indicates that the replenishment program is making a positive change in the quahog industry.

The regression models were based on the aggregated quarterly data for each of the five fishing areas. We used a multi-level, mixed model with fishing area as a random effect and quarter as a fixed effect. The random effect on fishing is based on the assumption that harvests from the different fishing areas will be different. By assuming a random effect on fishing areas we can control for the variance caused by different fishing area on harvest. The advantage of the hierarchical model is that we can also use a fixed effect; we used quarter of year as the fixed effect to control for any time variant effect on the fishing areas.

2.5 Regression Results

We considered two models, which differ in their specification of error terms. In the first model, we assumed a random intercept for each fishing area with assumption of normal distribution of error terms. In the second model we considered auto correlated regression (AR) models, since time series data usually have autocorrelated errors. Different AR models were considered, and an appropriate AR model was selected using the Likelihood Ratio (LR) test. Table 2.3 shows the results of the LR test on different AR models. The null hypothesis of the LR test assumes that the higher order of autocorrelation is equal to zero and the alternate hypothesis was the higher order autocorrelated model is not equal to zero. The results in the table indicates that AR (1) model is not nested within AR (2) model or AR (3) model, suggesting that AR (1) model is the better model to control for autocorrelation in the data. This shows that autocorrelation with a lag of 1 is appropriate to correct the autocorrelation bias present in the data.

The two models were compared using Akaike Information Criterion (AIC) values. The AIC value is used to select models from a set of models based on information theory. Kullback-Leibler distance, the distance between the model and the true value will be calculated. It measures the divergence of the probability model and the true sampling distribution. The model with lesser divergence would represent the distribution of the population better (Burnham and Anderson 2002). The statistical procedure suggests that the model with lower Akaike information criterion (AIC) values would explain the model better. In our study, the model with the AR (1) process has the lower AIC value and was considered the better model. Further description of the result was based on the results of AR (1) model.

The two models used in this study are represented in Table 2.4. The model represented as (1) is the model with assumption of normal distribution of error and the model (1) is AR (1) model. Our result from both models indicates that there is not a sufficient statistical evidence to prove that transplants have significant influence on the harvested quantity of quahogs. The confidence interval for the variable *transplanted quantity* was between -0.10 and 0.20, which indicates that for every one pound increase in quantity transplanted, there is 95% confidence that the increase in harvest quantity will not be more than 0.2 pounds. The model also shows that increasing the number of trips increases the probability of greater harvest, which was as expected. The interaction term between the number of trips and effort concentration gives us the direction and slope of the increase in harvest due to the number of fishing trips compounded by area characteristics, such as square feet of the fishing area and the number of open days. Catch from the previous time period will negatively affect harvest in the current time period. However, the extent of this decrease is only 0.03 pounds when there is an increase in one unit of harvest in the previous time period. The statistical significance of the random-effect parameters indicates that fishing areas are sufficiently heterogeneous in terms of their fishing productivity.

The quadratic relationship between the number of trips and quantity harvested was found to be significant as expected. Results indicate that increasing the number of trips to a fishing area increases the quantity harvested. Moreover, harvest will increase if there is an increase in fishing trips to fishing sites with lesser area and more open fishing days. The result shows that harvest in first quarter of the year was more compared to other quarters. This might give an indication that the transplant of quahogs may have an influence on total harvest. The transplanted sites will be opened for fishing after the conditional closure during the first quarter of a year.

The results obtained from the model shed some light on the effects of quahog stock transplantation. The model showed that there is no statistical evidence to prove that transplanted quahogs are significantly influencing the total harvest of quahogs. The participating fishermen claim that there is a 70-80% productivity from the transplanted quahog, whereas our analysis showed a contradictory result. The disproportionately small increase in quahog harvest from the transplant program can be explained by the structure of RI transplant program. The DEM collects quahogs from the restricted areas and stocks them to selected areas of some of the open fishing areas with the help of interested fishermen. After a seasonal closure of six months, the DEM allows only participating fishermen to harvest from these transplanted areas. This restricts the program's benefits to participating fishermen only. Since our study analyzed the effect of transplants at the industry level, the benefits from transplant activity are small because the participating fishermen constitute only one-third of the total fishermen.

2.6 Economic Feasibility

Net returns from the transplant operation were estimated to analyze the program's profit (Table 2.5). Revenue from transplant operations is received in the form of additional harvest obtained from the transplanted quahogs for the participating fishermen. Since the transplanted quahogs are allowed to be harvested only by participating fishermen, there was an average of 75 fishermen receiving revenue from the program. Thus, revenue received from a transplant area can be estimated as the product of predicted harvest, unit price of quahogs, and number of fishermen participating in the program. Using information on the number of transplantation sites, we can estimate the total revenue obtained from all transplant areas in the bay area. The transplantation of quahogs was carried out in only two of the five main fishing areas. Multiplying the revenue obtained from a transplant area by the number of fishing areas with transplantation we can estimate the total revenue generated from the transplant program.

Once the total revenue is estimated for the transplant areas, data on the total cost of transplant is essential to calculate net returns. The main costs include labor and fishing costs incurred for collecting quahogs from the prohibited areas and restocking them in open fishing areas. The total cost of the transplant program was obtained from DEM. The fishermen who participate in the transplant program would be paid for collecting the quahog and restock them to open fishing area. Deducting the total cost from the total revenue we can estimate the program's profit.

Our estimation revealed that the transplant operation is profitable for the shellfish industry. Total quarterly revenue obtained from the harvest of transplanted quahogs was $97,453, and total cost was $57,345, resulting in a net gain of $40,107. Based on the point estimates, the confidence interval for net benefit from the transplant program was calculated. The lower confidence interval showed that the transplant program was not profitable and there was a net loss of $ 130,435. The upper confidence interval showed that the estimated profit would be $ 210,649. Thus, the results indicate that at this rate of harvest, the transplant operation is economically viable for its participating fishermen.

2.7 Conclusion

Several interesting results regarding shellfish management strategies were determined from this study. Using data on harvested quantity of quahogs from the Narragansett Bay area, we investigated the economic performance of the transplant program conducted at two different main shellfish harvest areas. The estimated profit of the transplant program revealed that it is economically profitable for its participating fishermen. It is interesting to consider that the transplantation program is double paying the participating fishermen. The fishermen are paid to collect quahogs from a restricted area and stock them to an open fishing area and after six months, the authorities are only allowing those participating fishermen to harvest quahog from these transplanted sites. However, the result shows that there is no statistical evidence to prove a positive influence of transplantation on the quantity of quahogs harvested.

There are a few caveats in our analysis stemming from lack of data. The harvest data used in our study are aggregated to the five main fishing areas. However, DEM is conducting transplant operations in some specific subareas; therefore, if disaggregated harvest data were available, the influence of transplantation on total harvest would have been better predicted. In this study, a smaller coefficient for the effect of transplants might have occurred due to a lack of harvest data from subareas. In constrast, the expected conversion rate of the transplanted quahogs to harvest quantity is 75–80% (Mike McGiveney, quahog fisherman and President of Shellfisherman's Association, personal communication).

Moreover, DEM does not currently follow any procedure to differentiate the total quahog harvest from the harvest of transplanted quahogs. If we could have obtained data on the harvest of transplanted quahogs, we would have a better estimate of the relationship between transplanted and harvested quantity. Rectifying these issues is a goal of future research.

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Table 2.1. Shellfish Growing Areas in Rhode Island

Name	Area Code	Associated Main Area	Status
Upper Narragansett Bay Conditional Area A	1A	Upper Narragansett Bay	Conditional Open/Closure
Upper Narragansett Bay Conditional Area B	1B	Upper Narragansett Bay	Conditional Open/Closure
Conimicut Triangle	1C	Upper Narragansett Bay	Conditional Open/Closure
Mill Gut Management Area	1M	Upper Narragansett Bay	Conditional Closure
Greenwich Management Sub Area A	2A	Greenwich Bay	Conditional Closure
Greenwich Management Sub Area B	2B	Greenwich Bay	Conditional Closure
Greenwich Management Sub Area C	2C	Greenwich Bay	Conditional Closure
Potowomut Management Area A	3A	Potowomut Management Area	Open
Potowomut Management Spawner Sanctuary	3B	Potowomut Management Area	Closed
Potowomut Management Area C	3C	Potowomut Management Area	Open
Bissel Cove/Fox Island	3F	Bissel Cove/Fox Island	Open
High Banks Management Area	3H	Potowomut Management Area	Open
West Passage	3W	Potowomut Management Area	Open

East Passage	4A	Bristol Harbor	Open
Bristol Harbor Shellfish Transplant Area	4B	Bristol Harbor	Open
Mount Hope Bay	5A	Sakonnet Management Area	Conditional Closure
Sakonnet River	5B	Sakonnet Management Area	Open
Sakonnet Management Area	5C	Sakonnet Management Area	Conditional Closure
Kickemuit River Management Area	5K	Sakonnet Management Area	Conditional Closure
Block Island	6B	Coastal Ponds	Seasonal Closure
Ninigret Ponds	6N	Coastal Ponds	Open
Point Judith Ponds	6P	Coastal Ponds	Open
Quonochontaug Ponds	6Q	Coastal Ponds	Open
Winnapaug Ponds	6W	Coastal Ponds	Open

Source: This chart was prepared based on information from DEM (2008).

Table 2.2. Conversion Factors used to Convert Yield Units to Pounds

Species	Market Category	Conversion Factor		
		Count to Pound	Meat Pound to Pound	Bushels to Pound
Quahog				
	Littleneck	7	6.53	N/A
	Topneck	4.5	6.54	N/A
	Cherrystone	5.75	6.55	N/A
	Chowder	2.5	6.56	N/A

Note: For quahogs, quantity harvested is reported in count. Quantity is divided by the number given in the first column. For example, if the daily reported quantity of top necks is 100 counts, the quantity in terms of pounds is calculated by dividing reported quantity 100 by 4.5 (100/4.5) which is equal to 22.22 lbs. N/A indicates that the harvest quantity is not reported in that unit.

Table 2.3. Log-Likelihood Ratio (LR) Test of Different Autocorrelation Regression (AR) Models

Model	LR Statistics	Degrees of Freedom	p-value
AR(1) vs. AR(2)	0.02	1	0.90
AR (1) vs. AR(3)	5.55	2	0.14
AR(2) vs. AR(3)	2.80	1	0.05
AR(3) vs. AR(4)	5.53	1	0.08

Note: Each row indicates the LR test of two AR models using their log likelihood value post estimation of the models. Degrees of freedom depend on the number of residual lags considered in the AR model. The null hypothesis of the LR test was that higher order autocorrelation model is equal to zero.

Table 2.4. Effect of Transplants on Quahog Harvests from the Bay Area in RI using Mixed Models

Variable	Dep. Variable= Quantity of Quahogs Harvested (lbs.)	
	(1)	(2)
Quantity of quahogs transplanted (lbs.)	0.05	0.04
	(1.12)	(1.04)
Fishing effort	162.0***	164.10***
	(25.23)	(27.34)
Fishing effort x effort concentration	19.37***	19.17***
	(8.11)	(8.51)
Cumulative catch of previous time period	–0.02	–0.03**
	(–1.01)	(–2.03)
Quarter FE (base: 1st quarter)		
2nd quarter	21,363**	19,500**
	(2.09)	(2.45)
3rd quarter	27,254***	26,019***
	(2.7)	(3.02)
4th quarter	22,186**	22,464***
	(2.24)	(2.84)
Constant	3,132	5,076
	(0.32)	(0.57)
Autocorrelation specification	AR(0)	AR(1)
Observations	120	120
Adjusted R-Square	0.98	0.98
Log Likelihood	–1431.1	–1420.45
AIC	2882.19	2862.90

Note: Each column was derived from a separate regression model. The dependent variable is the quantity of quahogs harvested in pounds. Each regression model differs in the specification of error component. We used a multi-level, mixed model where the time variable quarter is the fixed effect; fishing area is random. In the first model, we assumed a random effect on intercept for fishing areas with no autocorrelation specification for error term. In the second model we assumed an autocorrelation model with a two-time period residual lag. The t-statistics are given in parentheses. The statistical significance at 99, 95, and 90% are represented as ***, **, and *, respectively.

Table 2.5 Economic Feasibility Calculation from the predicted quantity

	Transplant	Lower CI	Upper CI
Predicted Quantity	792.30 lbs	-594.22 lbs	2,178.82 lbs
Price of quahog (per lb)	$ 0.82	$ 0.82	$ 0.82
Total Revenue for a fisherman	$ 649.69	$ -487.26	$ 1,786.63
Total Revenue from a fisharea	$ 48,726.38	$ -36,544.78	$ 133,997.53
Total revenue from all fisharea	$ 97,452.75	$ -73,089.56	$ 267,995.07
Total Revenue From Transplant Operation	$ 97,452.75	$ -73,089.56	$ 267,995.07
Total Cost of Transplant Operation	$ 57,345.86	$ 57,345.86	$ 57,345.86
Net Profit from Transplant Operation	**$ 40,106.89**	$ -130,435.42	$ 210,649.21

Note: The calculation of net profit of transplant operations is based on the predicted harvest quantity from the mixed model. The predicted quantity of harvest from transplant operations was calculated by multiplying the coefficient of variables with average value of variables. The unit price of quahogs was obtained from the data. Since transplant operations were carried out in only two of the five fishing areas, total revenue from all fishing areas was restricted to revenue from the transplanted areas. The cost of the transplant program was obtained from DEM.

Figure 2.1. Distribution of Quahog Fishermen in Rhode Island Shellfish Harvest Areas

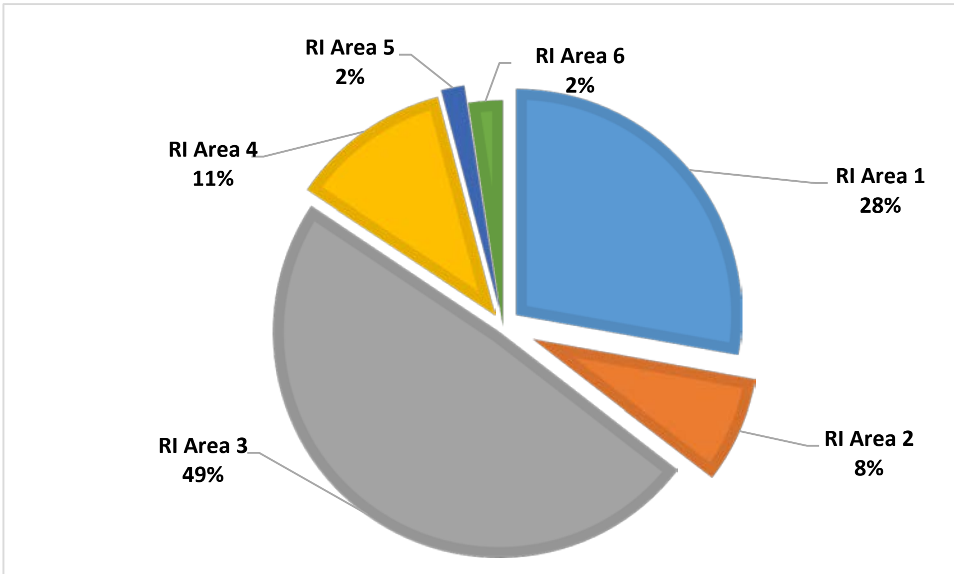
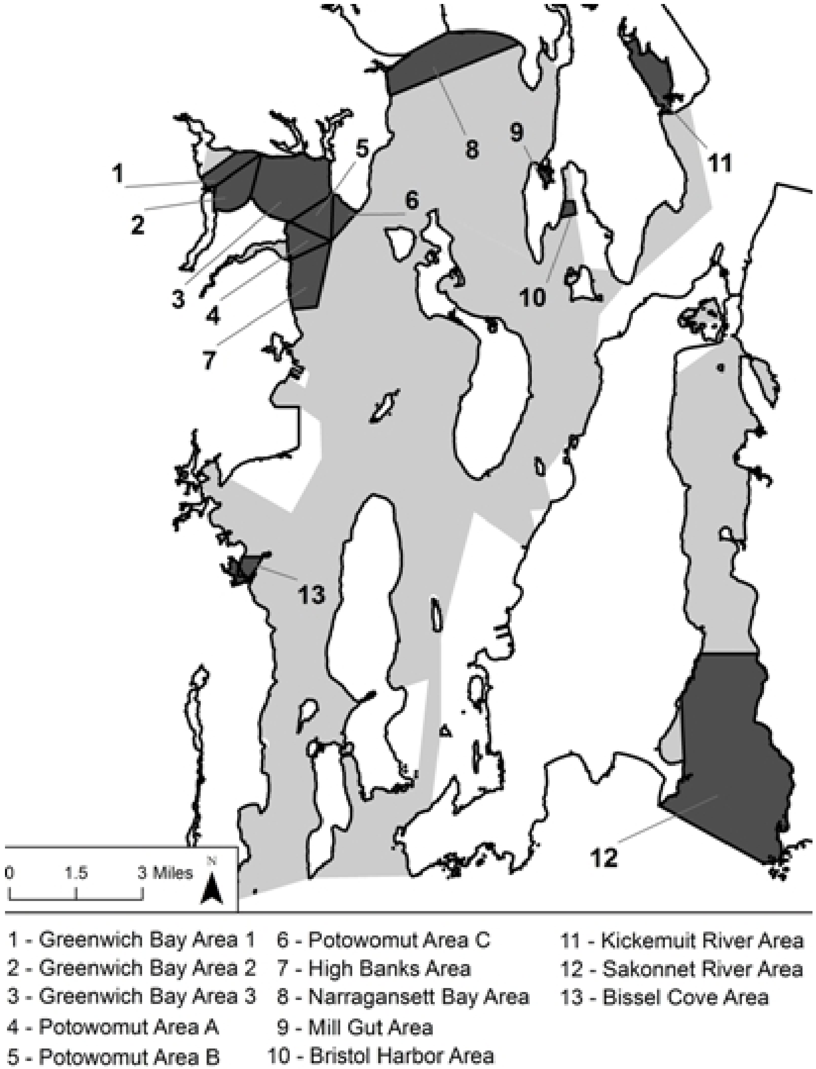


Figure 2.2 Harvest areas for shellfish in Narragansett Bay, Rhode Island



MANUSCRIPT-3

Effect of Oyster Farms on Housing prices in Rhode Island

To be submitted to Aquaculture Economics and Management

By

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Abstract

From 2000 onwards, United States saw an increasing trend for the shellfish aquaculture practices especially along the Northeast coast. Despite the majority of public supporting the shellfish aquaculture operations, these operations are sometimes opposed by local communities claiming the devaluation of housing property due to the construction of oyster farms. Since the uproar against the devaluing of housing property is directly affecting the lives of public, it is critically important to study the effect of construction of oyster farms on property value. A difference-in-difference (diff-in-diff) approach within a hedonic price model (HPM) was used to evaluate the effect of oyster farm on property values. We used a linear mixed specification with lot size as unit level fixed effect and city as random effect. Our housing sales data list all the housing transactions in Rhode Island between 2000 and 2013. The result showed that the diff-in-diff coefficient associated with interaction of distance bands and the construction of oyster farm, was not statistically significant. However, the result showed that if we consider only larger property, the construction of oyster farm would reduce the value of such property. This suggests that even though the people in general do not consider oyster farm in the neighborhood as a factor for purchasing house, the people who buys larger properties would consider the oyster farm as a significant factor. One of the limitations of this study is the relatively small housing transactions after the construction of oyster farms, which happened in recent years. Moreover, the analysis is not capturing the perception of those house owners who were not in the market. A revealed preference method such as survey would be necessary to capture the perceptions of all house owners.

3.1 Introduction

Bivalve shellfish aquaculture is a steadily growing and a strong segment in the United States and all over the world. Shellfish aquaculture production contributes for almost 20% of the total seafood production in the United States (Aquaculture 2014). Currently there are approximately 1,000 small farms all over the East coast with more than 60% in clam, 39% in oyster, and 1% in mussel production (Rheault 2013). Rhode Island alone has witnessed an increase of 61% in the number of farms over a period of 10 years (Buetel 2013). Until now, the authorized body in Rhode Island for monitoring aquaculture operations, the Coastal Resources Management Council (CRMC), has issued aquaculture leases to 52 farms in the state.

From 2000 onwards, United States saw an increasing trend for the shellfish aquaculture practices especially along the Northeast coast. The recent increase in the aquaculture practices in United States is attributed to its minor environmental quality degradation and influence on the primary and secondary productivity on water column (Rice 2008; Gallardi 2014). The public usually gives a supporting notion for starting new shellfish aquaculture operations nearby due to the environmental quality benefits they are going to acquire.

Despite the majority of public supporting shellfish aquaculture operations, these operations are sometimes opposed by local communities. Recently, the state of Massachusetts has issued a marine sanctuary to waters near Poppanesset Island and the cause for such an action is widely attributed to strong resistance of the richer communities for construction of oyster farms in Poppanesset bay (O'Sullivan 2014). Moreover, in a public meeting for seafood marketing held at Providence, Rhode Island in 2014, a discussion was carried out regarding the devaluing of property values due to the construction of oyster farms in the vicinity (Hiro Uchida, Associate Professor at URI, Personal Communication). Different reasons such as blocking the scenic water view, more water traffic, and more traffic in roads leading to the oyster farm might be the possible reason for devaluation of property claims.

Since the devaluing of housing property could directly affect the lives of the public, it is critically important to study the effect of construction of oyster farms on values of nearby residential properties. The outcome of this study will help understand the effects of aquaculture on nearby properties, and help the aquaculture leasing authority to design with better regulations on the leasing sites for culture operations. Moreover, the outcome of this study will help the governing bodies to frame new strategies to inform and educate the public regarding the effects of shellfish aquaculture to a locality.

Using economic theory, a cost-benefit analysis of oyster farming operations can be conducted by quantifying the negative externality caused from the operations of an oyster farm on nearby properties. After controlling for general housing price trends, analyzing the difference in housing value before and after the construction of aquaculture farm will be a good indication of the cost of the negative externality. The assumption is that if there is an adverse effect of oyster farms on the neighborhood, it would be reflected in the housing price. However, it is important to point out that impacts are not always reflected in housing prices especially if the buyer is not aware of such effects until he or she moves in to the new property. The non-response in housing price can also be due to a sorting effect that is, people with dislike towards oyster farms in their vicinity would sell the house to people with neutral preference for the farm in their neighborhood.

This study focuses on the effect of oyster farms on the housing value in Rhode Island. The rapid increase in the oyster and mussel culture since year 2000 and high population density would make Rhode Island an excellent site for such study. Since 2000, the aquaculture farms in the state have increased from 2 to 52 farms spanning almost all the coastal cities of the state. The rapid increase in the construction of oyster farms would enable us to obtain a good representation of the state for capturing the preference of public on housing property. The timing of the study is appropriate for Rhode Island since the state is currently working on setting an extensive management plan for farmed shellfish in the state.

A hedonic price model (HPM) was used to estimate the effect of oyster farms on nearby property values and a difference-in-difference approach within HPM was used to control for other factors that affect house price. We made the hypothesis that the houses that are closer to the farm will be more affected than the houses located far away, after controlling for other factors. Thus, estimating the difference in the property values of these two categories of houses before and after the construction of a farm provides an estimate of the degradation of the property value caused by the oyster farm. Moreover, proximity is considered as one of the major variables considered in research of similar settings (Herath and Maier 2010; Hoen et al. 2011; Gopalakrishnan and Klaiber 2014; Lang, Opaluch, and Sfinarolakis 2014).

3.2 Hedonic Price Theory and Previous Studies

The HPM is appropriate for competitively marketed goods with heterogeneous characteristics. Housing markets satisfy both the conditions and thus hedonic price models are widely used for analysis. When looking at housing markets, one of the limitations is the difficulty to capture all environmental characteristics because buyers may not consider some of them while purchasing a house. However, HPM can be used to analyze the effect of important environmental determinants that affect the price such as ocean view or distance to the ocean. A housing property can be categorized into three main types of attributes, namely, characteristics of the housing structure, lot characteristics, and the neighborhood characteristics of the property. The main advantage of using HPM is that the internal property attributes such as bedrooms, bathrooms, pool can be separated from the attributes associated with the location (Freeman 2003). Thus, using the housing market data, we use the hedonic price approach to analyze how the property prices are affected by environmental amenities associated with the location of the property. There is an extensive literature in resource economics studying the effect of environmental quality on housing prices. Predominantly, HPM have been used to evaluate different environmental qualities such as air pollution, noise pollution, view, neighborhood facilities (Chau and Chin 2002; Chau et al. 2004), and water quality (Gopalakrishnan and Klaiber 2014).

The HPM usually encounters challenges associated with omitted variable bias, autocorrelation, and endogeneity. When this class of models was first introduced, analyses were limited to only cross-sectional data to estimate the non-market goods such as environmental quality. The estimates from such models can only predict one point of the public's willingness to pay and identification problems were detailed in two studies (Brown and Rosen 1982; Mendelsohn 1985). Another issue with hedonic price models with cross-sectional data is the endogeneity problem of the variables and thereby issues related to the extraction of the marginal willingness to pay measure (Bishop and Timmins 2011).

Recent empirical research in this area specialized in correcting endogeneity and identification issues by utilizing the econometric framework for program evaluation (Imbens and Wooldridge 2009). In this line of research, Chay and Greenstone (2005) in their study used regression discontinuity method to estimate the cost of the Clean Air Act. Studies such as (Hoen et al. 2011; Lang, Opaluch, and Sfinarolakis 2014) used the difference-in-difference method to estimate the effect of wind turbines on nearby property.

Little research has been conducted to examine the cost of proximity of aquaculture farms on property value. The recent boom in shellfish culture could be one of the reasons for the lack of much attention in this area. Similar to this context, some studies have been conducted to check the willingness to pay (WTP) for nearest hog farming operations using HPM (Palmquist, Roka, and Vukina 1997; Murray 2009). These studies found that a livestock farming nearby would reduce the property value. However, neither of the studies used hedonic models with a program evaluation framework.

This study will present an econometrically sound analysis using the hedonic price model with a program evaluation difference-in-difference method to study the proximity effect of oyster farms on property value. This will be the first study in livestock farming operations to use the most recent development in hedonic price models to get a more unbiased estimate of the change in property value.

3.3 Theoretical Model

Hedonic Price Model

Evaluations of non-market goods are categorized into two main approaches: stated and revealed preference methods (Freeman 2003; Hanley and White 2007) differing in their approach to solicitation of the value. Stated preference methods measure the individuals' values for non-market goods by asking hypothetical questions regarding the value of non-market goods. Revealed preference methods seek to measure the value for goods by observing actual choices of individuals in the markets. One of the subcategories of the revealed preference method is related market methods. In the related market method, the value of the goods can be measured by observing the individual choices in the related markets. This subset of revealed preference methods are widely used to evaluate environmental quality, which can be reflected in market price (Pearce 2002).

The Hedonic Price model (HPM) in its original form or its extension- is one of the widely accepted revealed preference-related market methods to evaluate non-market goods like environmental attributes. It is a statistical method that identifies and quantifies the effect of house and environmental characteristics on the housing price by using extensive data on property sales transactions. Given the wide availability of housing transaction data and the fact that it captures most of the neighborhood and environmental characteristics of a house, hedonic price model can be considered as an appropriate model for evaluation of non-market goods.

The theoretical framework of HPM was mainly based on Lancaster's (1966) consumer theory and Rosen's (1974) model. In general, the HPM assumes that a product consists of a myriad of attributes and consumers derive utility from the consumption of each of the product attributes or characteristics and therefore they assume value for each of the attributes or characteristics (Sirmans, Macpherson, and Zietz 2005).

Assuming that the housing market is in equilibrium and buyers are price takers, an individual would choose a property if her utility is maximized given that the individual has full information on the prices of alternative property locations. Solving the utility maximization problem, we can hypothesize that the price of the residential property at location j (P_j) would depend on the price of structural characteristics of that property, price of neighborhood characteristics, and price of location-specific environmental amenities. The details of the maximization and derivation of the HPM are given in Appendix 1. The reduced form of the housing price can be represented as:

$$P_j = P(Q_j, N_j, E_j) \ ,$$

where Q_j represents the Structural characteristics of house j, N_j is the Neighboring characteristics, and E_j represents the environmental characteristics.

In the real world, the assumption of choosing the property with the optimal level of all attributes of a house is not satisfied. It is impractical to choose a property with all attributes to be at the optimal level. An individual usually chooses a property with a bundle of the attributes that maximizes her utility. This is one of the important shortcomings of HPM. In some cases, some of the attributes (eg: some of the neighboring characteristics such as structures) might not be in the bundle of attributes. Moreover, the individual does not have a full information about the housing market and she is only aware of the attributes that the market publishes.

Difference-in Difference Method

The change in environment characteristics happens during the course of time and therefore the effect of a change in environmental quality on housing price involves two time periods: before and after the change. The difference-in-difference (diff-in-diff) method is the appropriate method for impact evaluation when the data considered are a repeated cross-sectional data or panel data (Khandker, B. Koolwal, and Samad 2009).

The method is used when we are observing outcomes from two different groups at two different time periods (before and after the change). One of the groups is considered as treatment because in the second time period, this group is affected by the change, whereas the other group designated as control group did not receive any change in both time periods. As the name suggests, the method involves calculating two differences of the outcome. First, the average difference in outcome is calculated each for treatment and control group over the time periods which will remove bias from any time-invariant heterogeneity in the treatment and control group. Second, an average difference in outcome is calculated between the treatment group and control group to nullify any bias resulting from any permanent differences between the groups. The resulting outcome will give us a reliable estimate of the impact. We can formally write diff-in-diff as follows:

$$Y_{it} = \alpha + \beta T_{i1} t + \rho T_{i1} + \gamma t + \epsilon_{it}, \quad (1)$$

where Y_{it} is the observed outcome, T is a dummy variable representing treatment group, t is the dummy variable indicating time period, α is the constant, ρ will capture the differences between the treatment and control groups other than the change in environmental quality, γ will capture factors caused by the time trend, β is the diff-in-diff coefficient, which will capture the difference between the treatment and control group caused by the change in environmental quality, and ϵ is the error term.

3.4 Empirical Model

The HPM have been used extensively to estimate values associated with environmental quality. It has been used to estimate the effect of air quality (Lang 2012; Lang 2013; Bento, Freedman, and Lang 2013); (Pope 2008); crime rates (Bishop and Murphy 2011); power plants (Davis 2011); school quality (Cellini, Ferreira, and Rothstein 2010); wind turbines (Hoen 2010; Hoen et al. 2013; Lang and Opaluch 2013; Lang, Opaluch, and Sfinarolakis 2014a); effect of water quality (Gopalakrishnan and Klaiber 2014). Applying HPM to the housing market, the price of a house depends on housing characteristics, neighborhood characteristics, and environmental characteristics and can be expressed as:

$$House\ price = f(housing\ characteristics,$$
$$neighborhood\ characteristics,$$

$$environmental\ characteristics)$$

The buyer will consider housing characteristics such as size of the house, size of the lot, number of bedrooms, number of bathrooms, presence of air conditioner, swimming pool, etc. The neighborhood characteristics will also be considered when purchasing a house, such as nearness to city, crime rate, and quality of school. People may also value environmental characteristics such as scenic views, ocean view, air quality, absence of traffic, and quietness while considering house purchase. Based on the availability of the data, we considered the following characteristics for our study: lot size, living space, number of bedrooms, number of bathrooms, air conditioning system, condition of the house, distance to the shore, water view.

In this study we employ the diff-in-diff in HPM framework to estimate the effect of oyster farms on housing prices. The treatment we considered in the study is the distance of the house from the coastline. We created distinct distance bands and the distance band closer to the coastline were considered treatment group since these houses will be affected more likely with the construction of farm. Using the year of construction of each farm we created an indicator variable to specify the sale transaction took place before or after the construction of the farm. Formally, we can represent the model used for analysis as:

$$
\begin{aligned}
lnp_{it} = \alpha_{it} + \beta_{it}\, Treat * construct + \rho_{it}\, Treat + \gamma_{it}\, construct \\
+ \delta_{1it}\, lotsize + \delta_{2it}\, bed + \delta_{3it}\, bath + \delta_{4it} halfbath \\
+ \delta_{5it} pool + \delta_{6it}\, aircon + \delta_{7it}\, condi + \delta_{8it}\, larea \\
+ \delta_{9it}\, waterview + \delta_{10it} purpose + \mu_{1it} CITY + \mu_{2it} YEAR \quad (1) \\
+ \theta_{1it} biglot * construct + \theta_{2it} biglot * construct \\
+ \theta_{3it} biglot * construct * Treat + e_{it},
\end{aligned}
$$

where lnp_{it} is the natural logarithm of selling price of property *i* at time *t*, *Treat* is the treatment variable considered, which is distance of the property from coastline, *construct* is the indicator variable for the year of construction of oyster farm, *lotsize* is the size of the property in acres, *bed* is number of bedrooms, *bath* is number of bathrooms, *halfbath* is number of half bathrooms, *pool* is the indicator variable for swimming pool, *aircon* is the indicator variable for central air conditioning system, *condi* is the indicator variable for condition of the property, *larea* is the living space of house in square footage, *waterview* is the indicator variable for water view from the property, *purpose* is the primary use of the house, *CITY* is fixed effect for city of oyster farm, *YEAR* is fixed effect for year of housing transactions, *biglot* is the indicator variable for houses with larger lot size, and e_{it} is the error term.

We also analyze the impact of oyster farms on property value using a repeated sales model. The repeated sales model will only consider those houses transacted more than once during the study period. It can control for any random unobserved characteristics of the property by including a property level fixed effect to the model.

Since the housing characteristics are time invariant, all the structural and neighborhood characteristics will be dropped off from the model.

3.5 Data

Oyster Farm

We collected the details of the oyster farms operated in Rhode Island from the Coastal Resources Management Council (CRMC). CRMC issues leases for shellfish aquaculture operations after reviewing the annual water quality report issued by Office of Water Resources of RI Department of Environment and Management. It keeps the records of all the aquaculture farms in Rhode Island, and currently it has issued 52 leases for aquaculture operations of which the majority are oyster farms (Beutel 2013). Of the total leases, 42 oyster farms are currently in full operation (Figure 3.1).

Table 3.1 provides information of the 42 fully functioning oyster farms in Rhode Island, including the location of the farm and the year of construction of each farm. The first oyster farm was constructed in 1993 and there was not much increase in the oyster farm in later years of that decade. Since 2000, the number of oyster farms started increasing steadily and in year 2011 a total of 10 farms started farming operations. The last column of Table 3.1 details the distance of each farm to the closest housing property and it suggests that more than half of the oyster farms are located within 2.5 km from a real estate property.

Housing data

Our housing sales data include all the housing transactions in Rhode Island between 2000 and 2013. It contain information about the sales price, date of transaction, and housing characteristics such as year of construction, lot size in acres, living space in square footage, number of bedrooms, number of full, number of half bathrooms, presence of swimming pool, central air conditioning, and number of fire places. We selected only houses which are located within 2.5 km from oyster farms since our research interest is to estimate the consequence of oyster farm construction on housing property. Applying all these conditions, we have 4,237 observations in total.

Variables considered for the study

The dependent variable is the natural logarithm of the last transacted price of a property. The quarterly housing price index for the state of Rhode Island was obtained from the Federal Housing Finance Agency. The housing sale transaction prices were deflated using the housing price index of the last quarter of 2013 as base year.

The independent variables considered can be broadly categorized into three groups: variables directly related to oyster farms, structural characteristics of the property, and neighborhood characteristics that are not related to oyster farms. The characteristics directly related to oyster farms include distance from the property to coastline, an indicator variable for construction of the oyster farm and diff-in diff variable. The diff-in-diff variable is the interaction of distance from the property to coastline and the indicator variable for construction of farm. Using the year of construction of oyster farm data obtained from Coastal Resources Management Council (CRMC), a dummy variable was created for specifying housing transactions that took place after the construction of the oyster farm. The variable will take a value of one if the year of sales transaction took place after the construction of a farm and zero otherwise. A distance to the coastline was created using the location attributes of the house and nearest coastline. Different distance bands were considered to analyze the proximity effect of the oyster farm to house properties. The different distance bands considered were 0-0.75 km, 0.75-1.0 km, 1.0-1.25 km, 1.25-1.5 km, and 1.5-2.5 km with each category having 381, 368, 338, 570, and 2580 observations respectively. An interaction of distance classes and the construction of oyster farm was created to obtain the diff-in-diff variable which can be interpreted as price for houses sold after the construction of farms in each distance classes. Site visits revealed that housing property located in the further distance category do not have any ocean view and roads directly linked to the farm. Assuming a lesser degradation of value for these properties, the last distance category (1.5-2.5 km) was considered as the control group.

The housing characteristics category includes the various characteristics which might be considered important while purchasing a house. The variables in this category include living area in square footage, size of the lot in acres, number of bedrooms, number of bathrooms and number of half-baths, condition of the house, presence of central air conditioning, and presence of swimming pool. Of these variables presence of central air conditioning is a dummy variable, while the other variables are continuous variables. An indicator variable was created to specify the primary purpose of the house and there are five different uses considered in the study such as 1- family, 2-family, 3-family residence, condominium, and multi-building residence.

From the protest of the rich families mentioned in introduction, we would like to see whether there is a different impact on luxury houses as compared to more typical houses. Assuming that the luxury houses will have bigger property lot, we used the size of the lot as the proxy for those houses. We included a dummy variable for the bigger houses with a lot-size more than one acre and interacted with the indicator variable for construction of farm and distance of the property to the coastline.

Other interactions were also added to the model to analyze the combined effect of the variables considered. An interaction of water view and distance categories was created as a proxy for the view of oyster farm. However, we disregard the variable from the model because there were not sufficient water view observations in some of the distance categories.

Certain neighborhood amenities were also included to control for any effect of location on housing price. A dummy variable was created to specify whether the property has a water view from the property to control for effect of positive amenities on housing price.

The timeline of the housing transactions we used in this study spans over 10 years and therefore there are well known changes in housing markets over time. A year fixed effect was used to control for changes in the price over time and a city fixed effect was used to control for the effect of city on housing price. Census tract was converted to categorical variable and this variable was treated random within city.

Table 3.2 also gives the summary statistics of the characteristics of the property used in the study for each of the distance bands. The average price of the house in our dataset was $ 403,943 with an average lot size of 0.45 acres. The houses in the dataset have an average of 2.86 bedrooms, 1.84 full bathrooms, and 0.52 half bathrooms. The average living area of the property in this study was 1.78 square feet. The average distance to coastline is 0.35 miles which is expected since houses of our research interest are closer to the coast.

3.6 Results

The estimation results of the HPM using a linear mixed model are presented in Table 3.3[11]. Four different models have been compared with different combination of control variables. The models are summarized in Table 3.3. In all the models, we treat city and year as fixed effect and tract as random effect. The Model (1) in the table included city, year, and use of the property as fixed effect variables and is analyzing the effect of distance from the oyster farm on housing price. In Model (2), we added an interaction of dummy variable for bigger houses and dummy variable for construction of oyster farms to check the differential effect of the construction of oyster farms on larger properties. The Model (3) in the table includes an interaction for large properties at different distance bands and construction of oyster farms to include the differential effect of construction of oyster farms in different distance from the coast on larger properties.

In order to evaluate goodness of fit we report the R square values and for model selection the values of Akaike Information Criterion (AIC) was used. The

[11] A fixed effect model was carried out and the result is represented in Table 3.4. The lack of sufficient observations to add more fixed effects motivated us to choose a random coefficient model with city treated as random and year as fixed effect.

model with a lower value of AIC is considered as better model (Burnham and Anderson 2002). In our analysis, model (3) displays the highest R square and the lowest AIC, making it the preferred specification.

Our result suggests that considering all housing transactions in the study period, the houses in all distance bands of the treatment group have lower housing price compared to the control distance band (1.5-2.5 km). For example, houses located within 0.75 km from the coast have 38% lower house value compared to that in the distance band 1.5-2.5 km. The result also shows that construction of oyster farms do not have any significant influence on housing value of the property nearby. Our coefficient of interest is the coefficient associated with interaction of distance bands and the construction of oyster farms, which is represented as diff-in-diff coefficients in the table. None of the coefficients of the different distance bands in the treatment group are statistically significant except for the distance band 1.25-1.5. The result shows that the houses located within 1.25-1.5 km from the coast, the construction of oyster farms would increase its value by 14% compared to the distance band 1.5-2.5 km. However, based on the site visit, these houses have neither direct view nor direct access to the oyster farms. Thus, in general, the construction of oyster farms do not have any significant effect on the value of nearby housing property. A joint F-test was conducted to check whether the coefficients are jointly equal to zero and this null hypothesis is rejected (p-value =0.0009).

However, the coefficient associated with the larger property suggests that there is statistical evidence to prove that the housing values of these properties were adversely affected by the construction of oyster farms. Our result shows that the large property located between 0.75-1.0 km exhibits higher property value compared to the control group by 5%. The result also indicates that compared to the distance band 1.5-2.5km, the value of the larger properties located between 0.75-1.0 km would significantly decreased by 9% by the construction of oyster farms. This result clearly supports the claim that construction of oyster farms have decreased the housing value of the larger houses in some of the distance bands.

The coefficients associated with housing characteristics are represented further in the table. As expected, all the models show that all housing characteristics have a significant influence in housing price except for number of bedrooms. The magnitude of the coefficients suggests that houses with more amenities will have higher value as expected.

To summarize, the results from the model shows that while considering all houses in the proximity of oyster farms, there is no statistical evidence to show that housing values are impacted by the construction of oyster farms. However, considering only large property, the result showed that there is an adverse effect of oyster farms on housing property located between 0.75-1.0 km. The point estimates of the treatment effect for the distance within 0.75 km from the coast shows that the housing value will increase by 6% after the construction of oyster farm. The standard error of the coefficient was 5% indicating that we can be 95% confident that if there is an adverse effect of construction of oyster farm on the housing property in this distance band, the effect will be less than 10%. In practical terms, if the median value of a house located between 0.75-1.0km from the coast is $351,365. The decrease in the value of the property due to the construction of oyster farm would be less than $

35,136. For the closest distance band considered, the point estimate of the treatment effect was 6% and the standard error was 5%. Based on the point estimates, we can be 95% confident that if there is an adverse effect on the housing value due to the construction of oyster farm, it will be less than 8%. Now, consider the large properties located between 0.75-1 km. The median price of the large property at this distance band is $ 697,238. Our result shows that the construction of oyster farm would significantly influence the housing value. Based on the point estimate the decrease the property value with the construction of oyster farm was 9% which means that the property would be reduced by $62,751.

Repeat Sales Analysis

The results from the repeat sales model is represented in Table 3.5. A repeat sales model was analyzed by considering only the houses with more than one transaction during the study time. This subsetting of the data has reduced the number of observations by more than 60% (from 4237 to 1535). Three different models were represented for completeness and robustness. The estimates of the variables from the models did not vary much and for model selection following the AIC value, we selected model (2) as preferred model. The repeat sales results are consistent with the results we obtained from our unrestricted model. The houses located in the distance bands of the treatment group were 29-38% lower in value than the control group. The result also indicates that there is no statistical evidence to prove that construction of oyster farms have decreased the value of the nearby housing property. The result also indicated that there is no statistical evidence to prove that the housing located at different distance bands in treatment group were negatively influenced post the construction of oyster farms, compared to the control group. The result also shows that there is no statistical evidence to show that the larger properties will be impacted from the construction of oyster farm.

3.7 Policy Relevance and Conclusion

Policy Relevance

The goal of this study is to check whether construction of oyster farms along the coast adversely affects nearby property prices. One way to analyze the effect of industrialization of aquaculture on neighboring housing property is by analyzing the housing price by differentiating the housing property with number of farms located nearby. We thus differentiate the areas where more than two farms were located in the neighborhood and grouped as aquaculture developed area. Portsmouth and North Kingstown have more than 2 farms and was considered as the aquaculture developed city. Cities like South Kingstown, Newport, Middletown, Bristol, and Tiverton were having two or less oyster farms and were considered as less aquaculture developed cities. An indicator variable was created to differentiate these two categories of cities and was included in the model.

The result of the regression model is represented in Table 3.6. The result suggests that there is no statistical evidence to prove that the value of housing property adjacent to the farms (within 0-0.75 km) in aquaculture developed cities decreased after the construction of farms.

Conclusion

This research study analyzed the effect of oyster farms on the value of nearby houses. The results indicate that proximity to the oyster farms would significantly decrease the value of larger properties. However, considering all the housing properties, the proximity to the oyster farms will not be a factor influencing the housing price. The result from repeat sales analysis strongly supports the result that there is no statistical evidence to prove that there is a negative effect of construction of oyster farms on housing sales prices.

One explanation for our result for the general public is that people do not consider these environmental amenities while considering to purchase a house. The amenities or disamenities that directly affect their normal life like crime rate, presence of a school, or transportation facility would only influence the housing price. A similar study conducted by Lang, Opaluch, and Sfinarolakis (2014) to understand the effect of wind turbines on housing value in Rhode Island also found that there is no statistical evidence that the housing values is affected by construction of wind turbines in their vicinity.

Yet another explanation is that people value more those environmental amenities which are sustainable and less harmful to the environment. Oyster farming is one of the most sustainable aquaculture practices, which will help to improve the water quality by reducing the nitrogen load in the water. Wind turbine study conducted at URI also claims that people shows a positive attitude towards the green energy.

The result from the larger properties suggests that the house owners of large property do really care about activities in their neighborhood. This result is supporting the recent establishment of marine sanctuary in Poppanesset Bay in Massachussets following the opposition from the richer house owners in the neighborhood.

However, the result of this study does not guarantee the above conclusion. By analyzing the housing transaction data, we could only estimate the change in value for those houses which were in the market. However, this study could not capture the perceptions of those house owners who did not enter the market. Considering all the house owners near to the coast might have given us a different result. Moreover, CRMC includes a public opinion for the leasing process of oyster farms in Rhode Island. This provision will not allow the oyster farms in a neighborhood where there is an opposition for oyster farms. This perception will not be captured in the housing sale transactions. In order to capture the perceptions of all house owners, methods such as surveys need to be considered for future research.

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Table 3.1 Characteristics of Oyster farms in Rhode Island

Sl No.	Name	Location	Construction	Distance to closest property
1	Arnoux	Charlestown	4/4/2005	6.22
2	Arnoux	Charlestown	7/28/2009	7.03
3	Arnoux	Charlestown	12/4/2011	6.75
4	Behan	Charlestown	7/4/2010	8.08
5	Blank	Wickford	5/5/1997	0.22
6	Blank	Wickford	5/13/2001	1.75
7	Blank	Wickford	8/8/2001	1.16
8	Blank	Wickford	4/9/2006	0.35
9	Blank	Wickford	1/3/2009	0.34
10	Boucher	Saunderstown	9/14/2004	0.76
11	Brown	Portsmouth	6/3/2006	0.46
12	Brown	Portsmouth	7/1/2011	0.73
13	Clarendon	Little Compton	5/4/2003	0.33
14	Corey	Block Island	10/9/1997	21.50
15	DiPetrillo	North Kingstown	11/4/2006	1.67
16	Gardner	Westerly	5/9/1993	18.40
17	Goerner	Jamestown	2/4/2011	1.77
18	Hess	Portsmouth	11/2/2011	1.32
19	Jackson	Portsmouth	11/2/2011	0.38
20	Jackson	Charlestown	2/6/2007	6.55
21	Krause	Charlestown	6/3/1977	5.95
22	Littlefield	Block Island	12/4/2009	21.79
23	Mataronas	Narragansett	1/14/2011	1.70
24	McGhie	Portsmouth	1/2/2012	0.41

25	Melanson	Little Compton	6/5/1999	0.08
26	New Shoreham	Block Island	11/9/2011	20.48
27	Opton-Himmel	Charlestown	4/8/2011	7.54
28	Opton-Himmel	Charlestown	1/5/2010	7.63
29	Opton-Himmel	Charlestown	7/8/2011	7.26
30	Papa	Charlestown	7/2/2009	7.27
31	Papa	Charlestown	7/8/2011	7.26
32	Phillips & Deffley	Block Island	6/4/2013	21.43
33	Sebring	Portsmouth	7/1/1998	0.23
34	Silkes	Middletown	11/5/2000	0.80
35	Sipperley	Narragansett	3/3/2010	0.42
36	Soares	Portsmouth	4/9/2005	0.47
37	Thompson	Bristol	9/7/1998	0.36
38	Warfel	Block Island	2/6/2004	19.75
39	Warfel	Block Island	6/9/2003	21.35
40	Warfel	Block Island	3/4/2002	21.79
41	Warfel	Block Island	6/8/2009	21.26
42	Warfel	Block Island	6/2/2012	21.01

Notes: The locations of the oyster farms in the table do not represent the exact location, but it represent the city to which the oyster farms locate.

Table 3.2 Summary Statistics of variables considered for the study

	Bands of distance from Property to oyster farm					
Variables	<0.75 Km	0.75-1 km	1-1.25 km	1.25-1.5 km	1.5-2.5 km	Total
Price (,000s)	370.8	357.9	499.8	396.0	404.5	403.9
Lotsize (Acres)	0.36	0.33	0.44	0.35	0.50	0.45
Living Area	1.57	1.59	1.81	1.77	1.84	1.78
Bedrooms	2.66	2.72	2.81	2.72	2.95	2.86
Full Bathrooms	1.64	1.71	1.89	1.73	1.90	1.84
Half Bathrooms	0.44	0.42	0.52	0.57	0.53	0.52
Swimming Pool (1= Yes)	0.00	0.00	0.00	0.00	0.01	0.004
Air Conditioner (1= Yes)	0.23	0.26	0.41	0.47	0.34	0.35
Distance to coastline(Miles)	0.12	0.15	0.19	0.22	0.41	0.32
Water View (1= Yes)	0.03	0.00	0.00	0.03	0.05	0.03

Note: The values indicated are the mean value of each variable for each distance category.

Table 3.3 Effect of oyster farms on housing price using Diff-in- diff method in a mixed effect model

Variables	Dep. variable= log of housing price		
	-1	**-2**	**-3**
Intercept	12.7***	12.45***	12.46***
	(0.09)	(0.08)	(0.09)
Distance to coastline(Relative to 1.5-2.5 km)			
0-0.75 km	-0.58***	-0.36***	-0.38***
	(0.07)	(0.06)	(0.06)
0.75-1.0 km	-0.46***	-0.30***	-0.31***
	(0.06)	(0.06)	(0.06)
1.0-1.25 km	-0.41***	-0.29***	-0.29***
	(0.07)	(0.06)	(0.06)
1.25-1.5 km	-0.44***	-0.34***	-0.34***
	(0.08)	(0.08)	(0.08)
Construction of Oyster farm	-0.01	0.01	-0.0004
	(0.06)	(0.05)	(0.05)
Diff-in-diff (Distance to coastline x construction of oyster farm)			
0-0.75 km	0.08	0.04	0.06
	(0.06)	(0.05)	(0.05)
0.75-1.0 km	0.06	0.01	0.04
	(0.07)	(0.06)	(0.06)
1.0-1.25 km	0.08	0.03	0.03
	(0.08)	(0.07)	(0.07)
1.25-1.5 km	0.21**	0.14*	0.14*
	(0.09)	(0.08)	(0.09)
Housing Characteristics			
Bedrooms	0.001	0.01	0.01
	(0.01)	(0.01)	(0.01)
Living Area	0.24***	0.18***	0.18***
	(0.01)	(0.01)	(0.01)
Bathrooms	0.12***	0.11***	0.11***
	(0.01)	(0.01)	(0.01)
Half-bath	0.12***	0.11***	0.11***
	(0.01)	(0.01)	(0.01)
Pool	0.21**	0.13	0.13
	(0.09)	(0.08)	(0.08)
Air conditioner	0.11***	0.08***	0.08***
	(0.01)	(0.01)	(0.01)

Condition of house	0.23***	0.04	0.04
	(0.04)	(0.04)	(0.04)
Lot Size (in acres)	0.03***	0.01	0.01**
	(0.01)	(0.01)	(0.01)
Purpose of use (Relative to 1-Family Residence)			
2-Family Residence	-0.31***	-0.27***	-0.27***
	(0.05)	(0.05)	(0.05)
3-Family Residence	-0.31**	-0.43***	-0.43***
	(0.13)	(0.12)	(0.12)
Condominium	-0.08***	-0.04**	-0.04**
	(0.02)	(0.02)	(0.02)
Multi-Building Residence	-0.21	-0.17	-0.18
	(0.37)	(0.33)	(0.33)
Water View	0.47***	0.4***	0.4***
	(0.04)	(0.04)	(0.04)
Repeat Sales	-0.01	0.002	0.002
	(0.01)	(0.01)	(0.01)
Fixed Effects			
City (Relative to Bristol)			
Jamestown	-0.30**	0.1	0.09
	(0.13)	(0.12)	(0.12)
Little Compton	-0.41***	0.03	0.03
	(0.13)	(0.12)	(0.12)
Middletown	-0.61***	-0.17	-0.17
	(0.11)	(0.11)	(0.11)
Narragansett	-0.31***	0.12	0.12
	(0.11)	(0.10)	(0.10)
Newport	-0.18	0.15	0.14
	(0.13)	(0.12)	(0.12)
North Kingstown	-0.64***	0.17*	-0.17*
	(0.10)	(0.10)	(0.10)
Portsmouth	-0.58***	-0.15	-0.15
	(0.11)	(0.10)	(0.10)
South Kingstown	-0.33***	0.1	0.1
	(0.11)	(0.10)	(0.10)
Tiverton	-0.83***	-0.33***	-0.34***
	(0.11)	(0.11)	(0.11)
Year			
2001	-0.001	0.003	0.003
	(0.03)	(0.02)	(0.02)

2002	0.05*	0.05**	0.06**
	(0.03)	(0.02)	(0.02)
2003	-0.04	-0.01	-0.01
	(0.03)	(0.02)	(0.02)
2004	0.01	0.03	0.03
	(0.03)	(0.02)	(0.02)
2005	0.04	0.07***	0.07***
	(0.03)	(0.02)	(0.02)
2006	0.02	0.05**	0.05**
	(0.03)	(0.03)	(0.03)
2007	0.05*	0.06**	0.06**
	(0.03)	(0.02)	(0.02)
2008	0.02	0.03	0.03
	(0.03)	(0.03)	(0.03)
2009	-0.004	-0.01	-0.01
	(0.03)	(0.03)	(0.03)
2010	0.01	0.04	0.04
	(0.03)	(0.03)	(0.03)
2011	-0.02	-0.002	-0.003
	(0.03)	(0.03)	(0.03)
2012	0.01	0.02	0.02
	(0.03)	(0.03)	(0.03)
2013	0.06	0.08	0.08
	(0.10)	(0.09)	(0.09)
Interactions			
Construction X Large Property		-0.03	0.39
		(0.04)	(0.33)
Large Property X Distance to coastline			
0-0.75 km			0.34
			(0.24)
0.75-1.0 km			0.05*
			(0.29)
1.0-1.25 km			0.05
			(0.31)
1.25-1.5 km			-0.16
			(0.42)
Large Property X Post Construction X Distance to Coastline			
0-0.75 km			-0.42
			(0.34)

0.75-1.0 km			-0.09**
			(0.40)
1.0-1.25 km			0.08
			(0.51)
1.25-1.5 km			-0.002
			(0.53)
Observations	4177	4177	4177
Log Likelihood	-1708.3	-1304.4	-1295
AIC	3518.5	2714.9	2711.9
Adjusted R-Square	0.5471	0.5499	0.5501

Note: Each column comes from separate regression using a linear mixed model. First column represents hedonic price model with city and year fixed effects (FE) and census tract as random effect. The second column added a dummy variable for larger property. The Third column included interaction of larger property with construction of farm and distance bands. The Standard errors are shown in parentheses. ***, **, and * indicate statistical significance level at 1 %, 5%, and 10% respectively.

Table 3.4 Effect of oyster farms on housing price using Diff-in- diff method in a linear model

Variables	Dep variable= log of housing price		
	-1	**-2**	**-3**
Intercept	12.00***	11.98***	12.17***
	(0.07)	(0.07)	(0.07)
Distance to coastline(Relative to 1.5-2.5 km)			
0-0.75 km	-0.08*	-0.08*	-0.09**
	(0.04)	(0.04)	(0.04)
0.75-1.0 km	-0.09**	-0.09**	-0.10**
	(0.04)	(0.04)	(0.04)
1.0-1.25 km	0.03	0.03	0.01
	(0.03)	(0.03)	(0.03)
1.25-1.5 km	0.001	-0.003	-0.01
	(0.03)	(0.03)	(0.02)
Construction of Oyster farm	-0.12***	-0.13***	-0.08***
	(0.03)	(0.03)	(0.03)
Diff-in-diff (Distance to coastline x construction of oyster farm)			
0-0.75 km	0.13***	0.13***	0.12***
	(0.04)	(0.04)	(0.04)
0.75-1.0 km	0.11**	0.12**	0.08*
	(0.05)	(0.05)	(0.05)
1.0-1.25 km	0.07*	0.07*	0.07*
	(0.04)	(0.04)	(0.04)
1.25-1.5 km	-0.06*	-0.06*	-0.07**
	(0.03)	(0.03)	(0.03)
Housing Characteristics			
Bedrooms	0.003	0.004	-0.001
	(0.01)	(0.01)	(0.01)
Living Area	0.17***	0.17***	0.17***
	(0.01)	(0.01)	(0.01)
Bathrooms	0.10***	0.10***	0.10***
	(0.01)	(0.01)	(0.01)
Half-bath	0.09***	0.09***	0.11***
	(0.01)	(0.01)	(0.01)
Pool	0.03	0.02	0.15*
	(0.08)	(0.08)	(0.08)
Air conditioner	0.06***	0.06***	0.07***
	(0.01)	(0.01)	(0.01)

Condition of house	-0.01	-0.02	0.06
	(0.02)	(0.02)	(0.04)
Lot Size (in acres)	-0.01	-0.01	-0.01
	(0.01)	(0.01)	(0.01)
Water View	-0.41**	-0.41**	-0.27*
	(0.16)	(0.16)	(0.16)
Repeat Sales	0.02	0.02	0.02
	(0.01)	(0.01)	(0.01)
Fixed Effects			
Lot Size (Relative to 0-0.1 acres)			
0.1-0.2	0.12***	0.12***	0.10***
	(0.03)	(0.03)	(0.03)
0.2-0.3	0.17***	0.17***	0.17***
	(0.03)	(0.03)	(0.03)
0.3-0.4	0.18***	0.18***	0.20***
	(0.03)	(0.03)	(0.03)
0.4 and more	0.25***	0.25***	0.26***
	(0.03)	(0.03)	(0.03)
Year			
2001		0.01**	0.001
		(0.02)	(0.02)
2002		0.06**	0.06**
		(0.02)	(0.02)
2003		0.01**	-0.01
		(0.02)	(0.02)
2004		0.05**	0.03
		(0.02)	(0.02)
2005		0.07***	0.06**
		(0.02)	(0.02)
2006		0.03	0.03
		(0.03)	(0.03)
2007		0.07**	0.05**
		(0.03)	(0.02)
2008		0.05	0.03
		(0.03)	(0.03)
2009		-0.01	-0.03
		(0.03)	(0.03)
2010		0.04	0.02
		(0.03)	(0.03)
2011		0.03	0.01

		(0.03)	(0.03)
2012		0.06**	0.03
		(0.03)	(0.03)
2013		0.19**	0.12
		(0.10)	(0.09)
City (Relative to Bristol)			
Jamestown			-0.09
			(0.11)
Little Compton			-0.12
			(0.11)
Middletown			-0.27***
			(0.09)
Narragansett			-0.06
			(0.09)
Newport			0.004
			(0.11)
North Kingstown			-0.31***
			(0.09)
Portsmouth			-0.27***
			(0.09)
South Kingstown			-0.11
			(0.09)
Tiverton			-0.49***
			(0.10)
Purpose of use (Relative to 1-Family Residence)			
2-Family Residence	-0.31***	-0.31***	-0.25***
	(0.05)	(0.05)	(0.05)
3-Family Residence	-0.41***	-0.40***	-0.38***
	(0.12)	(0.12)	(0.12)
Condominium	0.15***	0.15***	0.13***
	(0.03)	(0.03)	(0.03)
Multi-Building Residence	-0.26	-0.24	-0.24
	(0.34)	(0.34)	(0.33)
Interactions			
Construction *Water View	0.43***	0.43***	0.42***
	(0.14)	(0.14)	(0.14)
Construction*Distance to coastline	0.31***	0.31***	0.28***
	(0.04)	(0.04)	(0.04)
Construction*Repeat Sales	-0.02	-0.02	-0.01
	(0.02)	(0.02)	(0.02)

Water View* Distance to coastline	0.26***	0.25***	0.34***
	(0.08)	(0.08)	(0.08)
Observations	4237	4237	4237
Adj R-Sq	0.6000	0.6000	0.6300
AIC	2977.18	2974.14	2657.24
BIC	3205.83	3285.37	3025.43

Note: Each column comes from separate regression using a fixed effect model. Lot size of property was included as unit level fixed effect. First column represents hedonic price model with Lot size, year, city, and purpose of property fixed effects (FE). The second column included a dummy variable for larger property. The Third column included interaction of larger property with construction of farm and distance bands. The Standard errors are shown in parentheses. ***, **, and * indicate statistical significance level at 1 %, 5%, and 10% respectively.

Table 3.5 Effect of oyster farm using Diff-in- diff method from Repeat Sales Data

	Dep. variable= log of housing price		
Variables	**(1)**	**(2)**	**(3)**
Intercept	13.04***	12.94***	12.94***
	(0.22)	(0.21)	(0.21)
Distance to Coastline (Relative to 1.5 to 2.5 km)			
0-0.75 km	-0.26***	-0.25***	-0.25***
	(0.10)	(0.10)	(0.10)
0.75-1.0 km	-0.26***	-0.27**	-0.29***
	(0.12)	(0.11)	(0.12)
1.0-1.25 km	-0.22*	-0.36***	-0.33**
	(0.13)	(0.13)	(0.14)
1.25-1.5 km	-0.39*	-0.44**	-0.45**
	(0.20)	(0.20)	(0.21)
Construction of Oyster farm	0.02	-0.002	0.004
	(0.11)	(0.11)	(0.11)
Diff-in-diff (Distance to coastline x Construction of Oyster farm)			
0-0.75 km	0.14	0.13	0.11
	(0.11)	(0.12)	(0.11)
0.75-1.0 km	0.09	0.06	0.06
	(0.15)	(0.14)	(0.14)
1.0-1.25 km	0.01	0.07	0.09
	(0.16)	(0.16)	(0.09)
1.25-1.5 km	0.14	0.19	0.20
	(0.22)	(0.21)	(0.22)
Year			
2001	-0.13**	-0.10*	-0.11**
	(0.06)	(0.05)	(0.05)
2002	0.02	0.04	0.04
	(0.05)	(0.05)	(0.05)
2003	-0.05	-0.01	-0.01
	(0.05)	(0.05)	(0.05)
2004	-0.01	-0.001	-0.01
	(0.06)	(0.05)	(0.05)
2005	0.05	-0.03	-0.03
	(0.06)	(0.05)	(0.05)
2006	0.05	0.07	0.07
	(0.06)	(0.05)	(0.05)
2007	-0.04	-0.01	-0.02
	(0.06)	(0.05)	(0.05)
2008	0.05	0.07	0.05
	(0.07)	(0.07)	(0.07)
2009	-0.06	-0.02	-0.02

	(0.06)	(0.06)	(0.06)
2010	-0.004	0.04	0.04
	(0.06)	(0.06)	(0.06)
2011	-0.11*	-0.08	-0.08
	(0.04)	(0.07)	(0.07)
2012	-0.03	0.02	0.01
	(0.07)	(0.07)	(0.07)
2013	-0.16	-0.10	-0.11
	(0.33)	(0.32)	(0.32)
Interactions			
Construction x Bigger Property		0.17	-0.13
		(0.10)	(0.67)
Bigger Property x Distance to coastline			
0-0.75 km			-0.08
			(0.75)
0.75-1.0 km			-0.0002
			(0.79)
1.0-1.25 km			-0.22
			(0.77)
1.25-1.5 km			-0.05
			(0.57)
Bigger Property x Post Construction x Distance to Coastline			
0-0.75 km			0.43
			(0.68)
0.75-1.0 km			0.18
			(0.74)
1.0-1.25 km			-0.001
			(0.72)
1.25-1.5 km			-0.58
			(0.68)
Observations	1535	1535	1535
Log Likelihood	-1006.1	-954.9	-951.0
AIC	2080.1	1981.9	1988.1
Adjusted R-Square	0.2531	0.2967	0.2974

Note: Each column comes from separate regression using a linear mixed model. The data used for this model consider only those house transactions happened more than one time during the study time. First column represents hedonic price model with year fixed effects (FE). The second column included a dummy variable for larger property. The Third column included interaction of larger property with construction of farm and distance bands. The Standard errors are shown in parentheses. ***, **, and * indicate statistical significance level at 1 %, 5%, and 10% respectively.

Table 3.6 Effect of Oyster farm on housing value in aquaculture developed cities

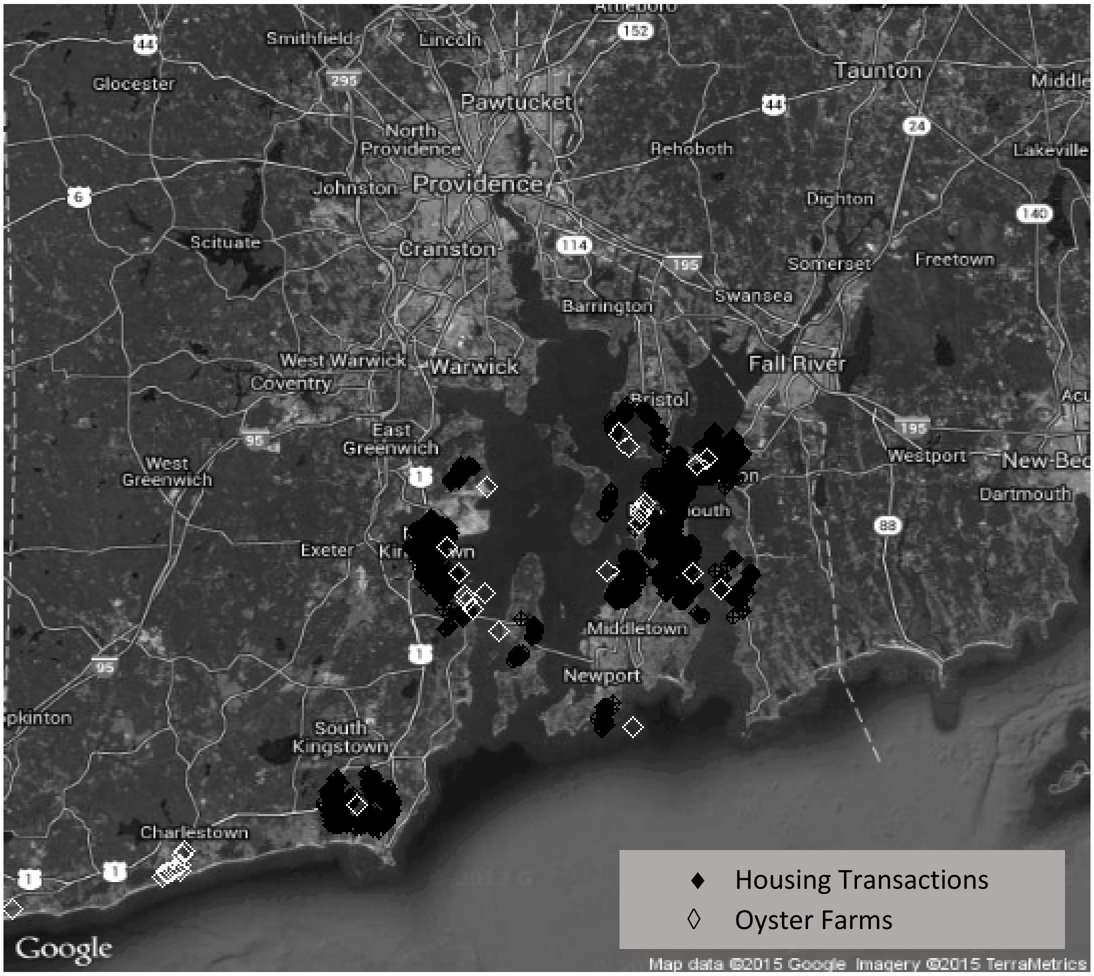
	Dep. variable= Log of house price		
	(1)	(2)	(3)
Intercept	12.3***	12.3***	12.30***
	(0.13)	(0.13)	(0.13)
Construction of Oyster Farm (COF)	0.01	0.01	0.01
	(0.10)	(0.10)	(0.10)
Aquaculture Developed City (ADC)	-0.03	-0.03	-0.02
	(0.14)	(0.14)	(0.14)
Interactions			
COF and ADC	0.003	-0.004	-0.01
	(0.11)	(0.11)	(0.11)
Difference-in Difference Estimate			
COF and Distance			
0.0-0.75 km	0.08	0.07	0.08
	(0.10)	(0.10)	(0.10)
0.75-1.0 km	-0.02	-0.02	-0.01
	(0.12)	(0.12)	(0.12)
1.0-1.25 km	0.20	0.21	0.19
	(0.13)	(0.14)	(0.14)
1.25-1.5 km	0.01	-0.01	-0.01
	(0.13)	(0.16)	(0.16)
ADC and Distance			
0.0-0.75 km	-0.09	-0.10	-0.11
	(0.11)	(0.11)	(0.11)

0.75-1.0 km	-0.13	-0.14	-0.14
	(0.11)	(0.11)	(0.12)
1.0-1.25 km	0.12	0.13	0.10
	(0.13)	(0.13)	(0.13)
1.25-1.5 km	-0.16	-0.18	-0.19
	(0.16)	(0.16)	(0.17)
COF, ADC, and Distance			
0.0-0.75 km	-0.12	-0.11	-0.10
	(0.12)	(0.12)	(0.12)
0.75-1.0 km	0.04	0.05	0.05
	(0.14)	(0.14)	(0.14)
1.0-1.25 km	-0.22	-0.23	-0.21
	(0.16)	(0.16)	(0.16)
1.25-1.5 km	0.18	0.21	0.22
	(0.18)	(0.19)	(0.19)
Bigger Property and COF	-0.01		0.42
	(0.04)		(0.33)
Bigger Property and Distance			
0-0.75 km		0.12	0.33
		(0.17)	0.24
0.75-1.0 km		0.09	0.58**
		(0.20)	(0.29)
1.0-1.25 km		0.29	0.23
		(0.24)	(0.31)
1.25-1.5 km		-0.03	0.10
		(0.26)	(0.43)
Bigger Property, COF, and Distance			

0-0.75 km			-0.42
			(0.33)
0.75-1.0 km			-0.92**
			(0.40)
1.0-1.25 km			0.63
			(0.51)
1.25-1.5 km			-0.30
			(0.54)
Observations	4237	4237	4237
Log Likelihood	-1280.20	-1279.10	-1272.0
AIC	2676.40	2680.20	2675.9
Adjusted R-Square	0.6132	0.6068	0.6084

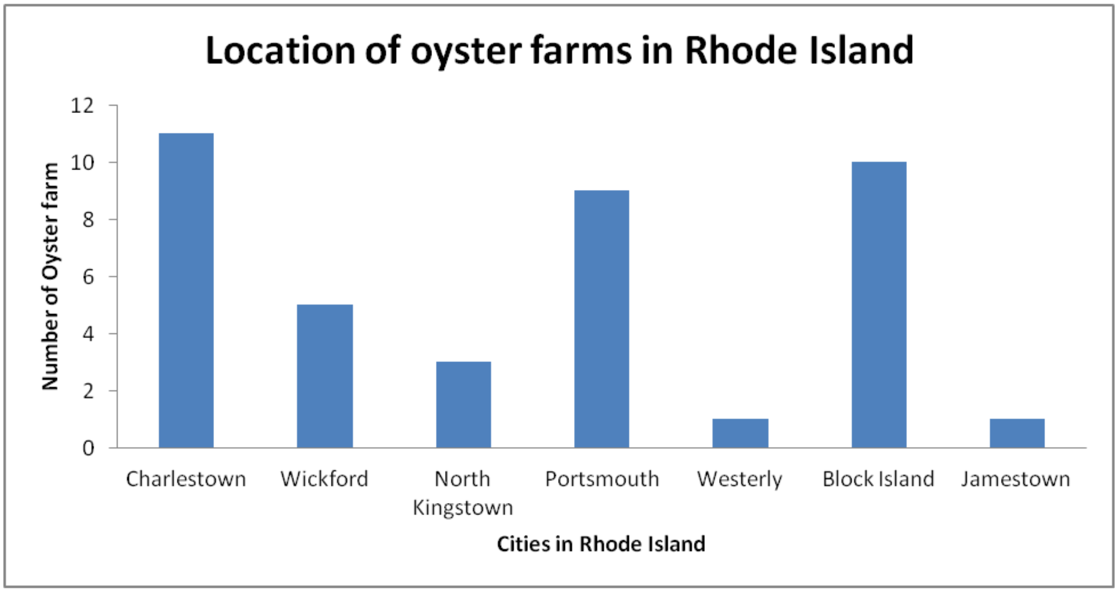
Note: Each column represents results from separate regression. The dependent variable was the log of deflated housing price. We analyzed the regression using a random parameter model where the tract was considered as random and year was considered as fixed effect. The three different models were represented differing in the interaction of large property. In the first column the large property were interacted with indicator variable for construction of oyster farms and in the second column the interaction of large property with the categorical variable distance to the coast. The last column extended the interaction of large property with both construction of oyster farms and distance bands. The standard errors are represented in parentheses. *, **, *** represents the coefficients with 10%, 5%, and 1% statistical significance.

Figure 3.1 Locations of Oyster Farms and Housing Transactions Considered for the study



Note: The image represents the location of oyster farm and property transactions of Rhode Island. The black diamond represents the housing property transactions and the transparent diamond details the location of oyster farms. We selected housing transactions within 2.5 km from the oyster farm for this study considering that distance from property to the farm would influence the housing price due to the construction of oyster farms.

Figure 3.2 Distribution of Oyster Farms in Rhode Island



APPENDIX 1

Hedonic Price Function Derivation

Let us assume that an individual derives his utility from the consumption of composite goods and amenities associated with a house. The amenities associated with the house would include structural characteristics, neighborhood characteristics, and location-specific environmental characteristics.

$$u = u(z, Q_j, N_j, E_j) \ ,$$

where *u* is the utility, *z* is the composite good the individual consumes, Q_j is the structural characteristics of the property at location *j*, N_j is neighborhood characteristics, and E_j is the location-specific environmental characteristics.

The utility maximization problem can be solved by setting the problem as Lagrangian by constraining to the individual's budget.

$$u = u\left(z, Q_j, N_j, E_j\right) \ s.t. M - P\left(Q_j, N_j, E_j\right) - z = 0,$$

where *M* is the total income and price of the composite good is assumed to be one. The first order condition for the choice of one of the amenities of the property can be given as

$$\frac{\partial u/\partial E}{\partial u/\partial z} = \frac{\partial P(Q_j, N_j, E_j)}{\partial N}$$

The partial derivative of the hedonic price function with respect to one of the amenities will give us the implicit marginal price of those characteristics.

CONCLUSION

This dissertation investigates three different issues pertaining to the management of shellfish resources in Rhode Island. The first chapter analyzes the relationship of price of a shellfish product to its own quantity landed and to other related shellfish products commercially harvested in the state. The results showed that all the shellfish species considered in the study were price inflexible, indicating that a huge harvest quantity of a product is required to change the price of that product. The analysis of the relationship between price of a shellfish product and quantity landed of other related shellfish products revealed that all the products considered in the study are substitutes to each other. However, the intensity of the relationship varies from product to product. The study also showed that different species have different peak season in a year.

The second manuscript analyzed the economic performance of the transplant program conducted in some of the fishing areas of Narragansett Bay. The result suggests that there is no statistical evidence to prove that the transplantation of quahog do not influence the harvest of quahogs in Narragansett Bay area. It also suggests that based on the current data, the transplant operation is profitable in economic terms.

The third chapter investigated the effect of construction of oyster farms on the neighboring housing property. The result showed that there is no statistical evidence to prove that the housing value is influenced by the construction of oyster farms. However, further study needs to consider other sources of information because the housing transaction data only capture the perception of the house owners who enter the market.

The results from all the three chapters are critical in terms of policy implication. The market demand study points that opening and closing of fishing areas due to the water quality issues will not change the price of shellfish much. Thus our result conclude that fishermen are over apprehensive about the loss of revenue due to intermittent closure of some of fishing areas. Moreover, the cross-price flexibility of the shellfish products suggests that these products are substitutes to each other. Therefore, if the dealer feel that one of the shellfish products are available in dominant quantity, they can switch to other shellfish products in order to maintain the revenue of fishermen. Moreover, the DEM can proceed with opening and closing of fishing area based on water quality without concerning much about change in the price of quahog.

The result from the second chapter reveals that transplant program is economically feasible, but the result did not show any evidence that the transplantation increase harvest of quahogs. However, the result points out that dispersal of larvae resulting from the transplanted quahogs will lead to reduction in quahog from all the fishing areas.

The results from the third chapter also have important policy implications. The results indicate that there is no statistical evidence to prove that constructing oyster farm in the vicinity would decrease the value of neighboring housing property. The lack of evidence can be due to two reasons. First, the people would consider only the characteristics that affect their daily life directly such as crime rate, water quality etc. Second, people do care for the ventures which are environmental friendly. However, other revealed preference methods such as surveys are necessary to examine whether the public supports shellfish aquaculture due to the environment benefit it provides by improving the water quality.

The three issues analyzed in this dissertation are time relevant topics in shellfish management in Rhode Island. The outcomes from this dissertation would be useful for managing bodies such as DEM and CRMC to come up with better and efficient strategies to manage the valuable shellfish resource in the state.

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