ECONOMIC EVALUATION OF TILAPIA AND TAMBAQUI PRODUCTION, CONSUMPTION AND SUPPLY CHAIN IN BRAZIL

by

Roberto Manolio Valladão Flores

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THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. Kwamena K. Quagrainie, Chair
Department of Agricultural Economics

Dr. Paul V. Preckel, Chair
Department of Agricultural Economics

Dr. Nicole O. Widmar
Department of Agricultural Economics

Dr. Maria Célia Portella
São Paulo State University

Approved by:
Dr. Nicole O. Widmar

Dedicated to Thayana, Rodrigo and Vivian

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TABLE OF CONTENTS

LIST OF TABLES 7
LIST OF FIGURES 8
ABSTRACT 9
CHAPTER 1. INTRODUCTION 11
1.1 References 14
CHAPTER 2. ECONOMIC ANALYSIS FOR LETTUCE AND JUVENILE TILAPIA PRODUCTION IN AN EXPERIMENTAL AQUAPONICS SYSTEM IN BRAZIL 16
2.1 Introduction 16
2.2 Data 19
2.3 Methodology 23
2.4 Results 25
2.4.1 Test of output-oriented technical efficiency 26
2.4.2 Standard non-parametric test of cost minimization 28
2.4.3 Test of profit (return above variable cost) maximization 28
2.4.4 Financial Indicators 30
2.5 Conclusions 34
2.6 References 35
CHAPTER 3. CONSUMER WILLINGNESS TO PAY FOR ATTRIBUTES OF FISH FILLETS IN BRAZIL 38
3.1 Introduction 38
3.2 Methodology 39
3.3 Data 42
3.4 Results 44
3.4.1 Fish consumption patterns 44
3.4.2 Knowledge about fish species 47
3.4.3 Results from econometric analysis 49
3.4.4 WTP across respondents with varying characteristics 52
3.5 Conclusions 54
3.6 References 55

CHAPTER 4. SPATIAL EQUILIBRIUM ANALYSIS FOR FISH SUPPLY AND DEMAND IN BRAZIL 59
4.1 Introduction 59
4.2 Methodology 60
4.3 Data 63
4.3.1 Survey of fish consumers 65
4.3.2 Fish farmers meetings 66
4.3.3 Processing facilities questionnaire 67
4.3.4 Google Maps 69
4.4 Results 69
4.5 Conclusions 74
4.6 References 75
CHAPTER 5. CONCLUSIONS 76
APPENDIX A. AQUAPONICS EXPERIMENT PICTURES 79
APPENDIX B. QUESTIONNAIRE APPLIED WITH CONSUMERS IN BRAZILIAN SUPERMARKETS 81
APPENDIX C. SOCIODEMOGRAPHIC, FISH CONSUMPTION AND FISH KNOWLEGDE VARIABLES FOR CONSUMERS WITH HIGHER AND LOWER PREFERENCES ON FISH ATTRIBUTES 85
APPENDIX D. DEMAND INITIAL VALUES ESTIMATION 88
APPENDIX E. ESTIMATION OF THE MATRIX OF PRICE SLOPES AND THE VECTOR OF INCOME SHIFTERS OF THE DEMAND FUNCTION 91
APPENDIX F. ONLINE QUESTIONNAIRE APPLIED WITH FISH PROCESSING FACILITIES IN BRAZIL 97
VITA 103
PUBLICATIONS 105

LIST OF TABLES

Table 2.1. Efficient treatments according to various nonparametric efficiency tests 27

Table 2.2. Profit maximization efficiency test and price sensitivity... 29

Table 2.3. Total initial investment for the aquaponics experimental system............................... 31

Table 2.4. Fixed operating costs for the aquaponics experiment... 32

Table 2.5. Cash flow and financial results for the profit efficient treatment 33

Table 3.1. Demographics results for subjects participating in the consumer survey................... 44

Table 3.2. Fish consumption characteristics for subjects participating in the survey.................. 46

Table 3.3. Fish knowledge of subjects participating in the survey 48

Table 3.4. Parameters from correlated RPL and mean WTP estimates for tilapia and tambaqui fillet for five Brazilian Regions 50

Table 3.5. Percentiles of OptOut, tilapia and fresh WTP (R$/kg) distribution per Brazilian region 52

Table 3.6. Highlights of sociodemographic, fish consumption and fish knowledge variables for consumers with higher and lower preferences on fish attributes 53

Table 4.1. Estimated annual demand (tons of processed fish).. 65

Table 4.2. Retailer final price per product per region... 66

Table 4.3. Fish farming inputs cost (R$/kg) 67

Table 4.4. Fish processing inputs cost (R$/kg).. 68

Table 4.5. Road distances (km) between supply and demand regions 69

Table 4.6. Percentage variation of quantity farmed and fish farming selling price due to parameters change in the spatial equilibrium model 71

Table 4.7. Percentage variation of demand and final price due to parameters change in the spatial equilibrium model 73

LIST OF FIGURES

Figure 1.1. Aquaculture production in Brazil in 2017 by species 14

Figure 2.1. Experimental design 20

Figure 2.2. Example of an aquaponic producing unit 22

Figure 3.1. Fisheries trade balance (US$ million) – 1997-2017 38

Figure 4.1. Brazilian map with producers and consumers points to be considered in the spatial equilibrium model 64

ABSTRACT

The Brazilian aquaculture sector has experienced growth in recent decades, and economic data from the sector is needed to characterize the supply chain, the consumer markets and financial indicators of fish producing units. Reliable statistical data on the Brazilian aquaculture sector is also needed to aid in the research efforts toward the sector. This dissertation analyzes data collected from experiments, suppliers and consumers of tilapia and tambaqui, the two most important fish farming species in Brazil, in three essays.

The first essay aims to fill a gap in the literature by assessing the economic returns to lettuce and juvenile tilapia production in an aquaponics system. Experimental data that varied fish stocking density and feeding rate when co-producing fish and lettuce in Brazil is analyzed. Using different nonparametric efficiency testing methods, a set of undominated technologies in the form of input mix, is identified. In addition, sensitivity analysis is used to assess the ranges for prices over which the choice of technology is robust. Results from the technical efficiency analysis show that it is possible to get marketable lettuce in synchronization with the fish production cycle using a reduced level of feed. At observed average regional market prices (0.18 R$/tilapia fingerling, 2.8 R$/kg for fish feed, 20 R$/kg for juvenile fish and 1.70 R$/lettuce plant), the highest profit alternative in the experimental design is from an initial stocking density of 250 fingerlings per m^3, feeding at the recommended rate, and harvesting on the 29th day. Sensitivity analysis indicates that the choice of best input combination is sensitive to only the prices of fish feed input and juvenile fish output. A complete financial analysis was based on this production strategy, and results indicate that a 10-year project is economically viable.

Consumer demand for tilapia and tambaqui product attributes is studied in the second essay. Seafood supply chains, from fish farmers to supermarkets selling direct to consumers, must understand consumer demand for product attributes to ensure production and availability of desired products. Consumers' willingness to pay (WTP) for tilapia and tambaqui fillets was estimated taking consumer demographics into account for each of the five Brazilian regions. A random parameters logit model was used to analyze data from discrete choice experiments conducted in-person at supermarket seafood counters. On average, Brazilian fish consumers prefer tilapia to tambaqui, and fresh to frozen fillets. Stated preferences were found to be related to knowledge about fish. This study is the first known analysis of national seafood preferences

considering factors such as product form, species, and familiarity with fish and fish products in Brazil.

In the third essay, a spatial analysis of the supply chain of tilapia and tambaqui is conducted with a focus on potential policy interventions and changes in the economic environment. The analysis is based on a partial equilibrium model of the sector and is the first comprehensive model of the aquaculture supply chain for Brazil. The demand component of the model is estimated econometrically using synthetic data based on the previous consumer choice experiment combined with secondary data on aggregate fish demand. The resulting demand system reflects asymmetric cross price impacts violating Samuelson's integrability condition. Rather than imposing symmetry during estimation, the model is formulated as a complementary problem. The spatially disaggregated model is applied to the evaluation of the impact of factors such as governmental incentives (subsides of fish feed), international oil price shocks (changes in the cost of transportation), increases in consumers' income (shifts in demand), and decreases in retailers' margins on the regional pattern of tilapia and tambaqui production and final consumption. Changes in transportation costs, impacted by oil prices or road improvements had little impact on market outcomes. A 10% reduction on retailers' gross margins decreased prices by 5.2% and increased quantity demanded by 5.4%, while an 8% reduction in fish feed costs due to tax cuts indicates, on average, 5.4% lower selling prices for farmers.

CHAPTER 1. INTRODUCTION

Recent estimates from the Food and Agriculture Organization (FAO) of the United Nations project world population to increase from the present 7 billion to 8.3 billion people by 2030, and 9.1 billion by 2050, necessitating a food production increase of 60% over the next 30 years (FAO, 2015). In addition, per capita income of the middle class is expected to increase worldwide, and rural-urban migration is expected to stabilize in the next 20 years (Embrapa, 2018). Increasing income is expected to drive preferences toward healthier food (Kearney, 2010), and fish is one of the healthiest proteins, given its amino acid and fatty acid composition (Jabeen and Chaudhry, 2011).

Approaches to meeting increased food production needs will likely vary across countries, and country-specific analysis of regional supply and demand can serve as important inputs to public policy. Global aquaculture production has increased nearly 1,100 percent in the last three decades, at an annual rate of 8.8% (FAO, 2015). Global fisheries production was 170 million metric tons in 2016, making fish the largest animal protein source. Capture fisheries have stabilized in the last 10 years at about 90 million metric tons (FAO, 2018). In 2011, aquaculture produced more protein than beef for the first time, and in 2013 people consumed more fish from aquaculture than from capture fisheries in the world (Matias, 2013). Many countries are investing in and improving their aquaculture supply chain, including Brazil (Carvalho Filho, 2018). A strong growth trend in aquaculture has been observed in Brazil with official data indicating 133% production growth in farmed fish between 2009 and 2013 (MPA, 2013; Carvalho Filho, 2014), and production reaching 547,163 metric tons of fish in 2017, according to the Brazilian Institute of Geography and Statistics (IBGE) (Carvalho Filho, 2018).

Brazilian aquaculture growth is bolstered by other factors such as the availability of water resources. Although currently underexploited, there is potential to expand aquaculture facilities in freshwater reservoirs of hydropower plants. There are 219 freshwater reservoirs in 22 states, covering a total surface area of 3.14 million hectares (Flores and Pedroza Filho, 2013). Some regions of Brazil experience warm temperatures throughout the year, and there is a large diversity of native fish and shellfish species, of which more than 60 species are farmed. There is a significant consumer seafood market, scientific knowledge to support production, and plentiful grain production, mainly corn and soybean, which are major components of fish feed.

The investment of more than one billion US dollars in fish production in the form of financing and loans by the Brazilian Ministry of Fisheries and Aquaculture (MPA) through the Fisheries and Aquaculture Production Plan is an example of the policy attention being given to the farmed fish production sector by the government. In 2009, the Brazilian Agricultural Research Corporation (Embrapa) opened a new research center at Palmas in the state of Tocantins, with more than 30 researchers and an investment of more than US$ 15 million focused on the technological demands of the aquaculture sector including fish health, reproduction, nutrition and socioeconomics of the main species farmed in Brazil (Flores and Pedroza Filho, 2013).

However, unlike countries such as China, Vietnam and Indonesia, the aquaculture expansion, though important, has not been targeted by the Brazilian government as a high priority. The Fisheries and Aquaculture Production Plan for Brazil, for example, was released just after the transformation of the MPA into the Secretariat of Aquaculture and Fisheries (SAP) under the Ministry of Agriculture Livestock and Supply (MAPA) in 2016. Later, the SAP was transferred to the Ministry of Industry, Foreign Trade and Services in 2017, but it has reverted to the MAPA as of 2019. These relatively rapid administration changes demonstrate the fragility of the politics and governance for Brazilian aquaculture.

Other issues must also be addressed to facilitate the expansion of the aquaculture industry. Scorvo Filho (2013) suggested the need for research on feeds and extension programming to inform producers regarding best practices. Reliable statistical data on the Brazilian aquaculture sector is also lacking; Dias Neto (2011) reported that there are misconceptions and biases in the official government data. For example, total aquaculture production is estimated based on the quantity of commercial fish feed sold using a linear regression, instead of data collection directly from fish farmers. In addition, detailed information on the links in the aquaculture supply chain, such as total production per region by species and input and output prices, is inadequate and questionable (Carvalho Filho, 2014). For example, the official statistics about aquaculture production in 2017 from IBGE, indicates a decline of fish farming output of 2.6% compared with the previous year, while the fish farming association with the largest membership in Brazil (Peixe BR) calculated an increase of 8% for the same period (Carvalho Filho, 2018). Market level information covering aspects such as the characterization of the supply chain, the markets and financial indicators of the performance of producing units is also needed. Public and private stakeholders involved in the development of the aquaculture industry need such information to guide their activities. In the private sector, farmers and industry need information, such as market potential, economic and financial analysis of the various production systems. For the public stakeholders, such information facilitates better design of incentives and policies.

To help address some of these challenges and to develop the sector, Embrapa is currently conducting a large national project entitled "Strengthening the Aquaculture Productive Development Policy in Brazil" (BRS-Aqua), a joint action with the Brazilian Development Bank (BNDES). The research in the BRS-Aqua project covers animal health, nutrition, reproduction, technology transfer and socioeconomics of the main species farmed in Brazil: tilapia, tambaqui, shrimp, and cobia. Besides being a graduate student of the Department of Agricultural Economics at Purdue University, I am also an Embrapa employee, and this dissertation is a partnership between both institutions with funding from Embrapa and Purdue. The objectives and results from this dissertation are part of the BRS-Aqua project.

This dissertation aims to provide useful contributions to the development of the supply chain and benefit actors such as farmers, industry, associations and government. This research utilized data collected from suppliers and consumers of tilapia and tambaqui, the two most important farmed fish species in Brazil. Figure 1.1 shows that tilapia and tambaqui represented 52% and 16%, respectively, of the total aquaculture production in Brazil in 2017. In addition, species like pacu, tambacu, tambatinga and pirapitinga (round fish) are very similar to tambaqui for economic purposes (market, production, inputs, taste etc.) and they represented 11% of production in the same year. Therefore, working on economic issues covering tilapia and tambaqui, this dissertation will address 79% of the aquaculture production and 88% of the farmed fish production in the country (Carvalho Filho, 2018).

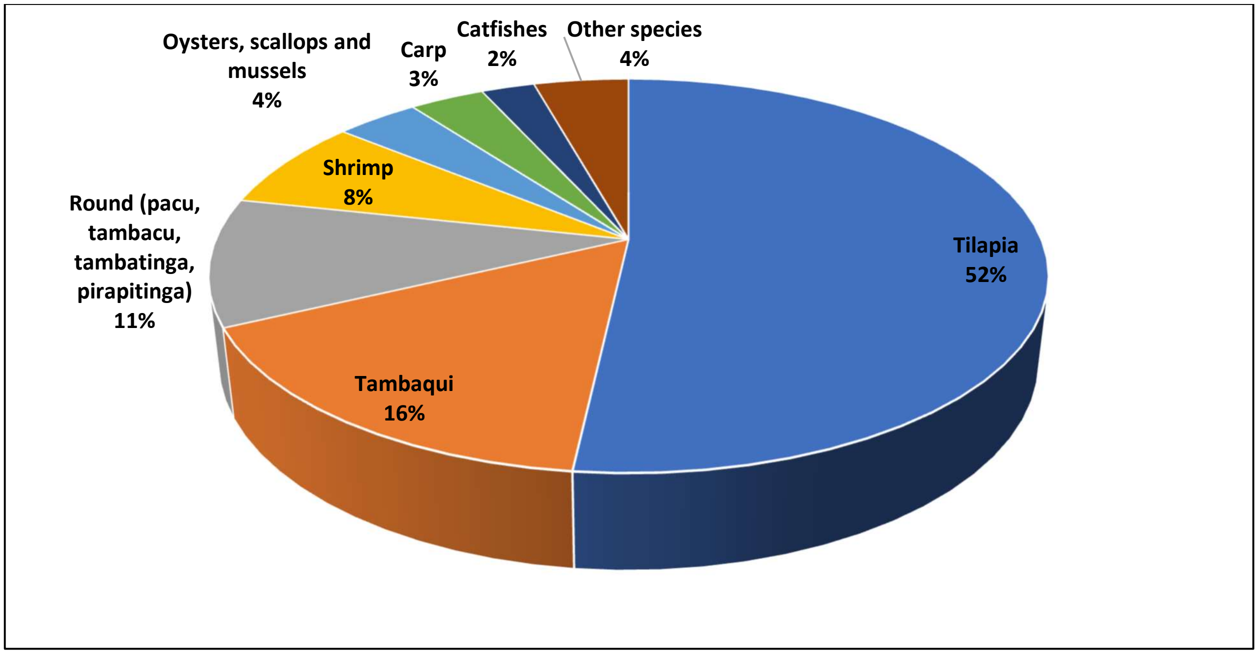

Figure 1.1. Aquaculture production in Brazil in 2017 by species

This dissertation is organized into three research essays. The first essay analyzes efficiency production of lettuce and juvenile tilapia in an experimental aquaponics system, an incipient activity around the world, but very attractive for areas with limited water resources, like the Brazilian Northeastern region. The second essay estimates consumers' willingness to pay (WTP) for product attributes (species and product form) of tilapia and tambaqui fillets taking consumer demographics into account for each of five Brazilian regions. Finally, the third essay considers the whole supply chain for both species from production through retail in the context of a spatial equilibrium model to evaluate the impact of government policies and entrepreneurs' decisions on the regional pattern of production and the final consumption.

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CHAPTER 2. ECONOMIC ANALYSIS FOR LETTUCE AND JUVENILE TILAPIA PRODUCTION IN AN EXPERIMENTAL AQUAPONICS SYSTEM IN BRAZIL

2.1 Introduction

Aquaponics involves the joint production of fish via aquaculture and plants via hydroponics in an integrated growing system, where the waste from fish production is converted by bacteria into useful nutrients for plants (Bosma et al., 2017). According to Goddek et al. (2015), "*the interlinking of aquacultural and hydroponic procedures allows some of the shortcomings of the respective systems to be addressed, and this represents a promising sustainable food production method*". Using this approach to fertilization, vegetable production may be considered as organic under an aquaponics system, and the higher prices often garnered for organic vegetables could provide economic incentives for commercial aquaponics production (Quagrainie et al., 2018). Today, most commercial aquaponics production is done in greenhouses or indoors where the environment is controlled, with a combination of techniques and tools that come from both the hydroponics and aquaculture systems (Love et al., 2015).

Aquaponics production continues to attract interest around the world, and researchers are trying to understand its economic feasibility. In a survey of aquaponics enterprises in the United States, Love et al. (2015) identify that the species of fish that is farmed by the greatest number of producers is tilapia. The survey also found that less than one third of those enterprises are economically viable. Bosma et al. (2017) reported that a good strategy for producers to have success in an aquaponics activity is to start with catfish, and after mastering the system's management, change to more expensive species such as tilapia for specific markets.

Other studies in different regions have analyzed profitability of aquaponics operations. Tokunaga et al. (2015), working with three aquaponics enterprises in Hawaii, analyzed the effects of factors such as use of electricity, investment, labor-intensity, and output price variability on economic viability and found that small-scale farms were viable and a good choice to farm plants (lettuce, tomatoes, cucumbers and beets) and fish (tilapia and Chinese catfish) for local markets. Bailey et al. (1997) and Baker (2010) reported similar results for tilapia and lettuce production in the U.S. Virgin Islands and Hawaii, respectively. The study for the U.S. Virgin Islands also found that small farmers garnered lower investment returns than larger farms. For the European case, Turnsek et al. (2020) report that most countries have observed the creation of aquaponics start-up companies, but aquaponic production in Europe is still incipient, and very few European operations are economically viable.

Emerenciano et al. (2015) assert that, in Brazil, aquaponics activities are just beginning to attract some interest and that the lack of interest so far is due to several factors including: misinformation, insufficient economic data and high initial investment costs. However, according to the authors, there are successful enterprises in other Latin American countries like Mexico and Chile where aquaponics production was motivated by water shortage problems, similar to the situation in some regions of Brazil. Although Brazil is known for its rich endowment of freshwater, which is about 12% of the freshwater in the world, water shortages are an important problem in the agriculture sector and a principal cause of food supply problems in some regions (Lemos and Oliveira, 2004). This is especially true in the arid zones (i.e., the Northeast region) and zones that become dry under certain situations (e.g., the Southeastern Region during El Niño years). According to Zou et al. (2016), aquaponics is extremely attractive for water short areas, because there is no wastewater discharge, and fresh water is required only for replenishment to replace evaporation. In addition, aquaponics is a clean system with no waste, which makes it good for all regions, including urban environments (Hundley et al., 2013).

The literature on Brazilian aquaponics is incipient (Hundley and Navarro, 2013; Braz Filho, 2014). While some experiments have been done, there are only a few relevant economic results. Most aquaponics research work done in Brazil has focused on production of tilapia and vegetables (Carneiro et al., 2015). An example is the study conducted by Pinho (2018) evaluating the aquaponics production of tilapia juveniles and lettuce using biofloc.[1] The economic analysis indicated economic viability with a minimum requirement of 63.5% of harvested plants visually suitable for marketing. Hundley (2013) tested different levels of fish stocking density for tilapia and basil production finding that high density levels result in better basil growth. Evaluating the economic viability of aquaponics for a different region, Kodama (2015) conducted an experiment in the Cerrado region in Brazil and used Monte Carlo sampling to simulate the yield variation in a

[1] Biofloc technology corresponds to the "growth of microorganism in the culture medium, benefited by the minimum or zero water exchange. These microorganisms (biofloc) have two major roles: maintenance of water quality, by the uptake of nitrogen compounds generating 'in situ' microbial protein; and nutrition, increasing culture feasibility by reducing feed conversion ratio and a decrease of feed costs." (Emerenciano et al., 2013)

model of the production system incorporating risk. The author found that an aquaponics system is economically viable and that labor is the main cost item. A comparison between aquaponics and hydroponics was also studied in Brazil by Carvalho et al. (2017). Results show that both systems fit well within the South region using tilapia and lettuce, and the high productivity level combined with low costs allow even small farmers to profitably invest in both activities.

Tilapia is the main species produced in Brazil representing almost 58% of total farmed fish production by weight (Carvalho Filho, 2018). However, in some regions of the country, the production of tilapia is prohibited by law and other native Brazilian species such as tambaqui and pacu have good potential due to their acceptance by Brazilian consumers (Flores et al., 2014). Ibrahim et al. (2015) analyzed the production of tambaqui juveniles in an aquaponics experiment conducted in the state of Tocantins. The authors found a positive correlation between the speed of water recirculation and higher fish survival rate, but they did not estimate economic returns. In the same way, using effluents of red tilapia and pacu in an aquaponics production with scallion and parsley, Pinho et al. (2018) show that pacu is an economically viable alternative.

The literature presented above shows some economic results from aquaponics. However, most of the studies used simple economic analysis like assessments of costs versus benefits and cash flow analysis. This research is based on the analysis of experimental data that raised fish and lettuce under alternative production input levels. Using different nonparametric efficiency testing methods, sets of undominated technologies, in the form of input mix and resulting output, were identified. Prices for input and outputs were then used to determine which input treatment and resulting outputs yielded the highest profit. In addition, sensitivity analysis was used to assess the ranges for input and output prices over which the choice of input treatment, or technology, is robust.

No previous research has applied nonparametric efficiency tests to aquaponics production in Brazil or elsewhere. However, several studies from other sectors have used this kind of analysis. Farrell (1957) discusses the problem of measuring the productive efficiency of an industry being important to both economic theorist and the economic policy maker. Using data from a U.S. industry, the author discusses the fundamental assumptions underlying nonparametric efficiency analysis, including issues of returns to scale and technical and price or allocative efficiency of an industry. In the same way, Charnes et al. (1978) targeted evaluating public programs through the development of measures of “decision making efficiency”, where programs mean a collection of decision units with common input and outputs. The authors conclude that there are a variety of ways to evaluate the efficiency of decisions in order to improve the control and planning of the activities.

Coelli (1995) discusses developments in the estimation of stochastic frontier functions and the measurement of efficiency. He does a comparison between econometric and linear programming approaches. The econometric approach is parametric and subject to specification error, while the linear programming approach is nonparametric, but generally lacks the statistical basis that the econometric approach has, which can be used for formal, statistical hypothesis testing. According to the author, there is no perfect method of measuring efficiency relative to an estimated frontier, but either the linear programming or econometric approaches present better measures of efficiency than only partial measures, like output per unit of land or labor.

Applying standard linear programming-based nonparametric efficiency tests, Preckel et al. (1997) assess the economic rationality of the behavior by fertilizer retailers – that is, these tests are applied at the individual firm level. They found that the fertilizer retailers in their dataset acted as variable cost minimizers, but not as revenue and profit maximizers. This result shows the importance of testing efficiency from a variety of perspectives.

There is economic potential for aquaponics activities in Brazil as well as associated environmental benefits given the sustainable characteristics of the production and the water shortage problem in some regions. Therefore, this essay aims to fill the gap in the literature by evaluating the economic returns to lettuce and juvenile tilapia production in an aquaponics system with different levels for key control variables.

2.2 Data

The data for the study were collected from an experiment with tilapia and lettuce conducted at UNESP (Sao Paulo State University) in July 2019 in Brazil. The experimental aquaponics facility has 16 producing units comprising one fish tank, associated equipment and three boxes of plants each. Each box has eight lettuce plants. Four different initial fingerling stocking density and four feed rates for a total of 16 input combinations were observed at the same time in a 30-day experiment. Figure 2.1 summarizes the experimental design and data collection process. For fish stocking density, the four levels were based on a beginning number of tilapia fingerling of 38 (100 fish/m^3), 57 (150 fish/m^3), 76 (200 fish/m^3) or 95 (250 fish/m^3). Fish were feed four times a day with Guabitech® for omnivores dry pellets containing 36% of protein. The feeding rate was calculated per treatment according to the stocking rate and recalculated every week considering the Guabitech's recommendations that provides a % of biomass feeding rate based on fingerling size. The experimental design varied this input by a percentage deviation from the recommended quantity. The four deviation levels are -3, -1.5, 0 and +3%. The literature shows the importance of measuring both variables in the production of tilapia in Brazil (Baccarin and Camargo, 2005; Rodrigues et al., 2016).

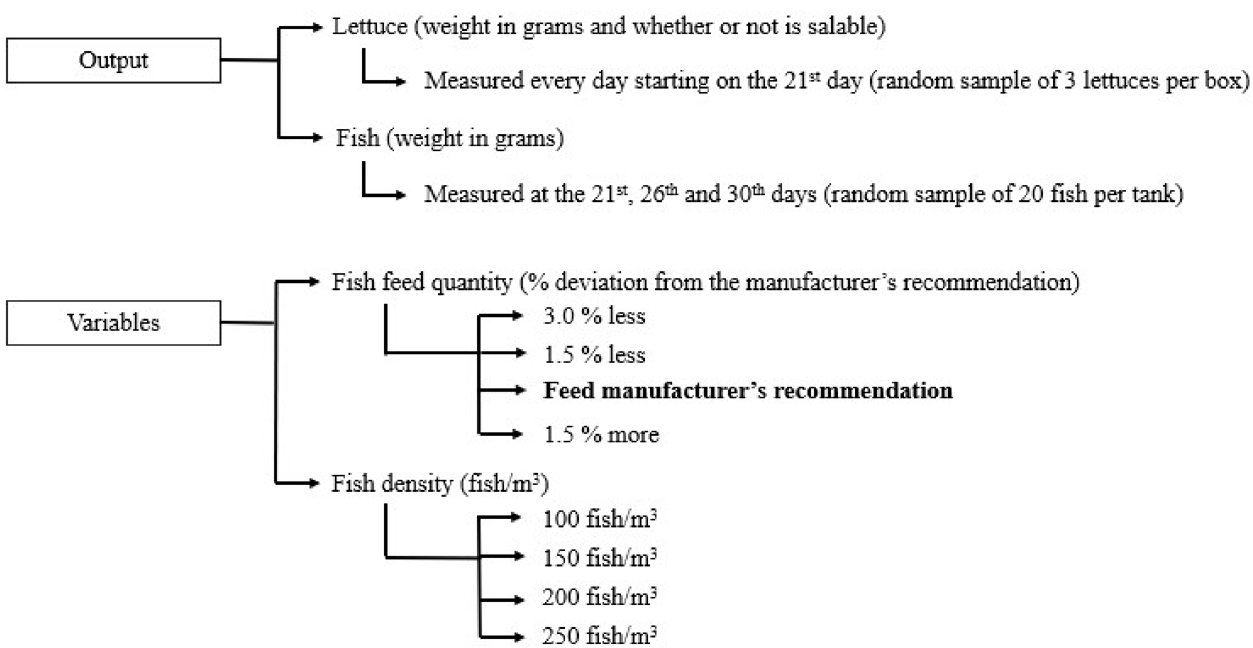

Figure 2.1. Experimental design

Lettuce output levels were measured every day starting on the 21st day of the experiment using nondestructive testing. A sample of 3 lettuce plants per box of plants were measured each day. The average of the results for the three measured plants was scaled up to find the total output of the producing unit for each day and each combination of input levels. Two output attributes of lettuce at harvest time are considered in the analysis; its weight (grams), and whether or not the plant is salable (based on the classification according to the size and color of each unit). Lettuce is the most common vegetable production used in aquaponics systems, and the previous knowledge provided guidance for the experimental design.

For fish, the output levels (weight in grams) were measured at the 21st, 26th and last day of the 30-day experiment. Weighing the fish every day was not feasible because it requires capturing, putting the fish under anesthesia, weighing and returning the fish to the tank, which stress the fish and may impair its subsequent food ingestion and growth. Therefore, the system of periodic weighing at days 21, 26 and 30 was used to determine the optimum day for harvesting by linearly interpolating the observed results for each combination of the input levels. A sample of 20 fish was measured for each aquaponic production unit during the days designated for measurement. As with the lettuce, the average of the results for the sample was scaled up to find the total weight of fish for the production unit.

The fish were grown to the juvenile stage. These juveniles, or large fingerlings, have a good market potential as inputs to a commercial fish grow-out operation and can be harvested within the 30-day production period. Because it is advantageous for fish farmers to buy juveniles rather than small fingerlings in order to "optimize the production structure and reduce the initial losses in grow-out due to predation in ponds and reservoirs" (Lima et al., 2013), there is a good market for juveniles. Cavero et al. (2009) has shown the economic advantages of producing grow-out fish from larger juveniles.

For some treatments with feed rates above the manufacturer's recommendation and lower fish stocking density, some floating feed was observed, indicating some feed wastage. Despite the observation that excess feed was being provided, the experiment was continued at the specified increased level of feed relative to recommendations, despite the waste. The feed waste was removed from the tank when observed because it would reduce water quality and could damage or clog the aquaponic system.

The overall structure used in the experiment was a greenhouse with 16 aquaponics systems composed by a 500 L fish tank with a useful capacity of 380 L; a 100 L settler device; a 180 L moving bed biofilter with area of 52.9 m^2 for bacterial attaching in which a Sarlobetter SB100A submergible pump was allocated (since the biofilter works also as a sump) and three hydroponic beds with a 117 L of suitable volume each using a total of 384 plants cups. Figure 2.2 shows a diagram of an aquaponics unit used in the experiment and Appendix A displays some pictures of the whole structure. (Note that the plant boxes in Figure 2.2 are different from the experiment being reported. In the diagram, there are 9 plants per box, instead of 8 plants per box.) During the experiment, nitrite and ammonia tests were carried out in each system to confirm that the levels were not toxic for tilapia. Also, the lettuce units received uniform treatment with respect to magnesium and iron, and hence these were not considered part of the experimental design.

Figure 2.2. Example of an aquaponic producing unit

The costs of inputs were based on the actual prices paid by the university staff that ran the experiment. It is justifiable because these items were purchased from standard providers at normal prices that would be representative of what a producer setting up an aquaponic operation would pay. Revenue per unit of output (lettuce and juvenile fish) was estimated based on information from potential buyers and averaged with the actual market data. Hence, there was no variation in prices across treatments in the dataset. Thus, the assessments of allocative efficiency applied below are not testing behavioral rationality of some economic agent, but rather is testing which treatments are consistent with either the minimization of cost given a particular set of output levels or which treatments are consistent with profit maximization.

2.3 Methodology

In this study, a test of output-oriented technical efficiency was applied across treatments from the experimental data and for each output. The idea behind the tests for each treatment is to assess the maximum amount of each output that could be obtained using a convex combination of the observed output vectors from the experimental data, where the same convex combination of inputs uses no more of any input than was used in that observation. The property of constant returns to scale is not assumed for any of the tests presented in this section. In addition, all inputs and outputs were normalized to a per year basis. This makes the treatments, which have different production cycles ranging from 21 to 30 days, comparable.

The first nonparametric efficiency test used is a directional test of technical efficiency with respect to a specific output in a multiple output production context. The mathematical formulation is:

$$\text{maximize} \quad \tau \tag{1}$$

$$\text{subject to:} \quad \sum_{i=1}^{I} u_{\tilde{k}i}\lambda_i \geq u_{\tilde{k}0}(1+\tau) \qquad \text{for one specific output } \tilde{k}, \tag{2}$$

$$\sum_{i=1}^{I} u_{ki}\lambda_i \geq u_{k0} \qquad \text{for every output } k, \tag{3}$$

$$\sum_{i=1}^{I} x_{ji}\lambda_i \leq x_{j0} \qquad \text{for every input j, and} \tag{4}$$

$$\sum_{i=1}^{I} \lambda_i = 1, \ \lambda_i \geq 0, \tag{5}$$

where u_{ki} is the level of output k for treatment i, x_{ji} is the level of input j for the treatment i, λ_i is the convexity weight for the treatment i, $\tilde{k}$ is the specific output whose efficiency is being tested, and τ is a scalar scaling factor to be maximized. In the output constraint, τ scales up the output of the specific output whose efficiency is being tested. The optimal objective value when this test is applied to an inefficient treatment will be greater than 0. A value of 0.1, for example, indicates that the treatment could have produced 10% more of output $\tilde{k}$ than what they were observed to produce given the level inputs that they used and requiring that they must produce as much as they did of the other outputs. The subscript 0 indicates the data for the treatment that is being tested.

The second test is a standard non-parametric test of cost minimization without the assumption of constant returns to scale. This asks whether the output for a treatment could have been produced using a convex combination of treatments where the weighted sum of inputs achieved a lower cost than was observed for the treatment, when inputs are valued at the level confronting the treatment. Effectively, this asks whether the treatment's output could have been produced at lower cost. The linear program for this test is:

minimize	$\sum_{j=1}^{J} w_{j0} x_j$		(6)
subject to:	$\sum_{i=1}^{I} u_{ik} \lambda_i \geq u_{k0}$,	for every output k, and	(7)
	$\sum_{i=1}^{I} x_{ji} \lambda_i \leq x_j$,	for every input j, and	(8)
	$\sum_{i=1}^{I} \lambda_i = 1,\ \lambda_i \geq 0$,		(9)

where w_{j0} is the input j price, and x_j is the level of input j in the convex combination. In accord with the first set of constraints, every feasible combination of input/output vectors must produce at least as much of all outputs as was produced by the treatment being tested. This test calculates the minimum level of cost that can produce the observed output vector. If this minimum level of cost is less than the cost observed, then this treatment is not cost efficient. Because prices are uniform across treatments and the treatments are the result of an experimental design, there are no behavioral conclusions to draw from these tests. Rather, these tests indicate that for a given output mix (observed for the treatment being tested), there is an input configuration associated with a treatment that can produce the outputs at lower cost.

The third efficiency test is for profit (return above variable cost) maximization with both multiple outputs and inputs. All outputs and inputs are now treated as variable. The linear program for this test is:

maximize	$\sum_{k=1}^{K} p_{k0} u_k - \sum_{j=1}^{J} w_{j0} x_j$		(10)
subject to	$\sum_{i=1}^{I} u_{ik} \lambda_i \geq u_k$	for every output k,	(11)

$$\sum_{i=1}^{I} x_{ji}\lambda_i \leq x_j \qquad \text{for every input } j\text{, and} \qquad (12)$$

$$\sum_{i=1}^{I} \lambda_i = 1,\ \lambda_i \geq 0, \qquad (13)$$

where p_{k0} is the price for output k. This problem is quite similar to the cost minimization test except that the output configuration is allowed to adjust as well. Here, because the prices do not vary across treatments, there is only a single problem to be solved for the profit maximization test, and it will identify the treatment(s) that produces maximum profit, as well as the level of profit. (There will only be multiple optimal treatments if this linear program has multiple optimal solutions.)

In addition to these non-parametric tests for efficiency, an additional analysis was applied to determine how the optimal technology identified with the profit test changes as the relative values of inputs and outputs change. These impacts are assessed using standard linear programming sensitivity analysis. The results indicate how far the price of each input or output can be changed before the solution changes, holding the prices of all other inputs and outputs constant.

As mentioned, there is no price variation for inputs or outputs across the treatments. This is the set of prices around which the sensitivity analysis is performed. In addition, these prices and the treatment found to be efficient with the profit maximization test is used to develop a detailed cash flow analysis for the production system. Financial indices like Internal Rate of Return (IRR), Net Present Value (NVP), Payback Period, and Benefit/Cost (BC) are calculated using a 6% annual discount rate for a 10-year project. These indices allow us to analyze the economic viability of the best treatment at given prices.

2.4 Results

Each treatment is a combination of different levels of the two inputs, fish stocking density and feed rate, plus a third input – time, which is represented by the harvest day. Since each input has four levels tested and there are ten potential harvest days for the output measurements, there is a total of 160 treatments being compared. The treatments are numbered from 1 to 160, but in each of the tables presented here, the harvest day, the stocking density and the feed rate levels are also displayed to facilitate comparison and interpretation. It is also displayed the total feed given, total number of fingerlings as inputs, lettuce production and fish production. Considering that different harvesting days will result in a different number of production cycles per year, the inputs and outputs are converted to an annual basis.

2.4.1 Test of output-oriented technical efficiency

The test employed for technical output efficiency is weak in the sense that, by testing for each output one at a time, while limiting all inputs to no more than what was used by that treatment and requiring at least as much of the other output is produced, will tend to find a large number of efficient treatments. For the fish output, 37 treatments were observed to be technically efficient as indicated in Table 2.1. For the inputs, the efficient treatments have lower feeding rates with very few treatments with rate level of +1.5% relative to feed manufacturer's recommended level. During the experiment, treatments with high feeding rate (+1.5%) showed feed waste that floated on the water in the fish tanks. Thus, it is not surprising that other treatments with lower feeding rates are more efficient.

The 28 treatments that are technically efficient in producing the lettuce output are also indicated in Table 2.1. It is observed that all of the treatments that were technically efficient in producing lettuce were also technically efficient in producing fish. This test considered the weight of the lettuce units, regardless of whether the lettuce was salable or not, assuming a homogenous product. The results show that many of the treatments are efficient. Most of the treatments that were efficient for fish production, but inefficient for lettuce production had initial fingerling stocking density at the lowest level – 100 fingerlings/m^3 (Table 2.1, columns 3, 7 and 8). This suggests at the low level of fish stocking density, the effluent in the water is insufficient to provide adequate nutrients to the plants.

Table 2.1. Efficient treatments according to various nonparametric efficiency tests

Treatment	Harvest day	Density (fish/m^3)	Feeding rate (%)	Total Feed (kg/year)	Total Fingerlings (#/year)	Lettuce production (kg/year)	Fish production (kg/year)
1	21	150	-3.0	19.6	945.7	4.0*	42.2*
2†	21	100	0.0	37.1	630.5	3.5*	54.6*
3	21	250	-1.5	50.0	1576.1	5.3*	80.0*
5	21	200	-3.0	24.9	1260.9	6.6*	54.6*
9†	21	250	1.5	107.8	1576.1	5.9*	100.3*
10	21	100	-3.0	15.2	630.5	4.0*	31.3*
21	22	200	-3.0	25.3	1206.1	7.3*	52.8*
26	22	100	-3.0	15.4	603.0	4.2	31.3*
42	23	100	-3.0	15.5	577.9	4.3	31.3*
58	24	100	-3.0	15.7	554.8	4.3	31.3*
62	24	250	0.0	79.0	1387.0	9.1*	98.2*
68	25	150	0.0	54.8	800.2	8.0*	72.4*
74	25	100	-3.0	15.8	533.5	5.2*	31.3*
78	25	250	0.0	80.6	1333.7	9.0*	99.3*
84†	26	150	0.0	56.8	770.6	8.1*	73.4*
87	26	200	0.0	52.9	1027.4	8.7*	73.0*
90†	26	100	-3.0	16.0	513.7	4.5*	31.3*
91	26	150	-1.5	36.7	770.6	10.0*	53.5*
94†	26	250	0.0	83.1	1284.3	9.2*	100.3*
96†	26	100	-1.5	25.7	513.7	7.5*	39.2*
106†	27	100	-3.0	16.2	495.4	4.2	28.9*
112	27	100	-1.5	26.3	495.4	7.7	38.2*
122†	28	100	-3.0	16.4	478.3	4.7	26.6*
128	28	100	-1.5	26.9	478.3	8.2	37.3*
138†	29	100	-3.0	16.5	462.3	4.8	24.5*
142‡	29	250	0.0	89.7	1155.8	10.7*	92.9*
144	29	100	-1.5	27.4	462.3	8.7	36.5*
147	30	250	-1.5	58.0	1118.5	11.6*	74.0*
148	30	150	0.0	63.5	671.1	10.7*	59.4*
149	30	200	-3.0	27.2	894.8	10.5*	43.9*
151†	30	200	0.0	60.1	894.8	12.2*	65.1*
152	30	100	1.5	60.1	447.4	7.3*	47.7*
153	30	250	1.5	124.7	1118.5	8.3*	97.0*
154†	30	100	-3.0	16.7	447.4	5.2*	22.6*
155†	30	150	-1.5	39.4	671.1	12.5*	50.5*
158†	30	250	0.0	91.6	1118.5	10.9*	90.8*
160†	30	100	-1.5	27.9	447.4	9.2*	35.7*

*Notes: For outputs, Lettuce production and Fish production (columns 7 and 8), a * indicates that the treatment is technically efficient with respect to that output, i.e., a higher level of that output could not be achieved with a convex combination of the observed treatments without either using more Total Given Feed or Total Fingerlings or reducing the production of the other output. For treatments (column 1), a † indicates cost efficiency, i.e., given the levels of input costs, a lower level of cost could not be achieved with a convex combination of the observed treatments without reducing the level of at least one of the outputs. A ‡ for a treatment indicates that the treatment is cost efficient and also profit efficient, i.e., for the given input and output prices that treatment (number 142) yields the highest profit of all the treatments.*

2.4.2 Standard non-parametric test of cost minimization

Table 2.1 also displays the results for a non-parametric test of cost minimization (column 1) where prices are set to the levels paid at 180 R$[2]/thousands of tilapia fingerlings and 2.80 R$/kg for fish feed. Most of the cost-efficient treatments, 13 out of 15, were harvested on the 26th–30th day (columns 1 and 2). This suggests that the treatment must have had sufficient time for the outputs to develop in order to be efficient.

Complementing the technical tests, treatments with lower feeding rates are assessed as efficient more frequently than those with higher rates. This suggests that it is possible to produce the same level of output with a system that uses smaller quantity of inputs and consequently yields a lower cost. Just as the treatments that are efficient in producing lettuce are also efficient in producing fish, the cost efficient treatments are efficient in producing fish.

2.4.3 Test of profit (return above variable cost) maximization

The profit maximization efficiency test result is displayed in Table 2.2. In this case, all outputs and inputs are treated as variable and the same inputs prices from the cost minimization test are used. To value output, the juvenile fish price used in the test, according to the average regional market, is 20 R$/kg. For lettuce, it is used unit of salable plants instead of weight as output unit. This approach is important because lettuce is sold by the unit and will only be acceptable for sale if the color and size reach certain commercial requirements. The price used in the test, according to the average regional market, is 1.70 R$/lettuce.

[2] R$ represents the Real, the Brazilian currency. At the time when this document was written R$ 1.00 equaled US$ 0.24.

Table 2.2. Profit maximization efficiency test and price sensitivity

Price interval (R$)	Most efficient treatment	Harvest day	Density (fish/m^3)	Feeding rate (%)	Lettuce production (kg/year)	Fish production (kg/year)
Feed						
0 - 0.009	**142**	**29**	**250**	**0**	**10.7**	**92.9**
0.009 - 0.011	94	26	250	0	9.2	100.0
0.011 - 0.014	78	25	250	0	9.0	99.2
0.014 - 0.018	3	21	250	-1.5	5.3	80.0
0.018- 0.035	5	21	200	-3	6.6	54.6
0.036 - 0.037	1	21	150	-3	4.0	42.2
Higher than 0.037	10	21	100	-3	4.0	31.3
Fingerling						
0 - 1.25	**142**	**29**	**250**	**0**	**10.7**	**92.9**
1.25 - 1.62	84	26	150	0	8.1	73.4
Higher than 1.62	152	30	100	-1.5	7.3	47.7
Lettuce						
0 - 1.3	94	26	250	0	9.2	100.0
Higher than 1.3	**142**	**29**	**250**	**0**	**10.7**	**92.9**
Juvenile						
0 - 0.002	160	30	100	-1.5	9.2	35.7
0.002 - 0.005	139	29	150	-1.5	11.6	51.2
0.005 - 0.026	**142**	**29**	**250**	**0**	**10.7**	**92.9**
0.026 - 1.459	94	26	250	0	9.2	100.0
Higher than 1.459	9	21	250	1.5	5.9	10.0

Notes: The profit maximizing treatment at regional average prices of 20 R$/g for juvenile, 1.7 R$/plant for lettuce, 180 R$/thousands of tilapia fingerlings and 2.80 R$/g for fish feed is treatment 142. The price ranges are the ranges over which the indicated treatment remains optimal, holding all other prices constant. The ranges for prices that include the regional average base prices are indicated in bold in the table.

The most profitable treatment at market average base prices is treatment #142 (harvest day 29, density 250 fish/m^3 and zero variation on the quantity of feed recommended). (See Table 2.2.) The higher initial stocking density of fingerlings is advantageous for profit because it produces more fish juveniles given enough nutrition and thus increases the revenue. In addition, the manufacturer recommended feeding rate is preferred, because it is enough to support fish growth while limiting feed waste. Harvesting on the 29th day of the experiment is preferred over harvesting on the last day because more lettuce units were salable on the next to last day than the last day.

Sensitivity analysis of the choice of optimal treatment to prices of inputs and outputs reveals several things. First, the optimality of the base treatment (#142) is generally quite robust with respect to output prices. The price of juvenile fish must be reduced by a factor of more than four in order to get a change in the optimal treatment. However, if the price of juvenile fish increases by about 30 percent, it would be optimal to switch from the base treatment (#142) to treatment #94, which has zero lettuce output but the second highest juvenile fish output of all the treatments. Further increases in the price of juvenile fish have no impact until it becomes unreasonably high – nearly 75 times the base price. For the lettuce price, roughly a 30 percent decrease is enough to cause a switch to another treatment. From the above results, there are two key regimes of interest – production at the optimal treatments #142 and #94. The driver of change is the price of juvenile fish relative to the price of lettuce, and if that price ratio increases 30 percent, then the treatment switches from #142, which jointly produces juvenile and lettuce, to #94, which only produces juvenile.

The optimality of the base treatment is likewise fairly robust with respect to input prices. The change in the price of fingerlings needed to induce a change in optimal treatment is quite large – a factor of seven increase. The choice of treatment is similarly insensitive to the price of feed. The change in the price of feed needed to induce a change in the optimal treatment is over a factor of three. It is interesting that the treatment that is more profitable when the feed price increases just enough to make #142 non-optimal, shifts the optimal treatment to #94. It implies that, prices must individually be changed quite substantially to change the optimal configuration of inputs from the levels in treatment #142.

2.4.4 Financial Indicators

The results reported here utilized inputs and outputs from treatment #142, and also focus on the base prices that were used for the profit test. The choices of inputs, outputs and prices allow a more detailed analysis of the cash flows and assessment of the returns to fixed factors versus the investment costs of the aquaponics system.

The economic viability analysis considers all the investment costs in the experimental structure in addition to the operating costs. Table 2.3 presents the investment items, quantity used, price and total cost. A total of R$ 91,225.95 was needed to have all the structure ready to run the experiment. In addition, the useful life for each item was estimated to account for the schedules for replacement of these productive assets in the final financial indices. Linear depreciation was used. The investment items presented mimic an actual aquaponics enterprise of similar size. The only item that could be added is land, but it is not considered here because the value of land varies with pressure for alternative uses. Thus, the analysis presented here are appropriate for a producer that has idle land available for an aquaponics system.

Table 2.3. Total initial investment for the aquaponics experimental system

Item	**Quantity**	**Price**	**Total**	**Useful life (years)**
Fish tanks	16	R$ 199.00	R$ 3,184.00	10
Plastic barrel	16	R$ 60.00	R$ 960.00	5
Support pumps	4	R$ 189.20	R$ 756.80	5
System pumps	16	R$ 50.00	R$ 800.00	5
Biomedia	2.5	R$ 4,100.00	R$ 10,250.00	10
Decanter	17	R$ 250.00	R$ 4,250.00	5
Hydroponics boxes	48	R$ 100.78	R$ 4,837.44	10
Styrofoam	48	R$ 18.11	R$ 869.28	3
Hydroponics cups	384	R$ 0.39	R$ 149.76	3
Greenhouse Infrastructure	1	R$ 21,985.68	R$ 21,985.68	20
Electrical installations	1	R$ 16,998.00	R$ 16,998.00	10
Hydraulic installations	1	R$ 10,372.78	R$ 10,372.78	10
Electric generator	1	R$ 8,846.00	R$ 8,846.00	10
Stand	1	R$ 3,713.66	R$ 3,713.66	5
Blower	1	R$ 3,252.55	R$ 3,252.55	5
Total			**R$ 91,225.95**	

In this essay, operating costs are divided in two types, fixed and variable. Fixed costs are the items that do not vary with the level of production. These cost items are also separated into three groups according to how frequent they are used. Therefore, there are items with the cost displayed per day, per 4-day period, and per harvest. This classification is important because the treatments being compared have different harvest days and the sum of these items is used to calculate the total annual cost according to the number of days in the aquaponics cycle and therefore how many times it is repeated in a year. Table 2.4 shows the fixed operating costs according to this classification. Total energy and water costs are estimations according to the measured daily use in the experiment multiplied by the price per unit (kW and liter) in a rural area. Labor cost was calculated considering the average of 2 hours per day of work in the experiment multiplied by the governmental minimum wage in Brazil (6.25 R$/hour) at the time of the experiment.

Table 2.4. Fixed operating costs for the aquaponics experiment

	Quant.	Un.	Price		Total	
Per day						
Energy - lights	3.3	kW	R$	0.30	R$	1.00
Energy - pumps	6.93	kW	R$	0.30	R$	2.08
Energy - heaters	16.7	kW	R$	0.30	R$	5.00
Water	0.033	m^3	R$	4.30	R$	0.14
Labor	2	hour	R$	6.25	R$	12.50
Lettuce supplementation - Magnesium	2.24	ml	R$	0.01	R$	0.02
Lettuce supplementation - Iron	1.34	ml	R$	0.01	R$	0.01
Total per day					**R$**	**20.75**
Per 4-day period						
Ammonia test - water quality	0.32	kit	R$	26.40	R$	8.45
Nitrite test - water quality	0.32	kit	R$	25.60	R$	8.19
Total each 4 days					**R$**	**16.64**
Per harvest						
Lettuce seedlings	384	unit	R$	0.095	R$	36.48
Total per harvest					**R$**	**36.48**

Annual costs for fish feed and fingerlings are taken from the profit optimizing treatment of the previous section, as were yields. Table 2.5 presents the final annual cost and the other results for the system based on treatment #142 (harvest at the 29th day, density 250 fish/m^3 and zero variation on the quantity of feed recommended). Total annual variable cost is R$ 7,389.36 (R$ 3,474.72 is fingerlings cost and R$ 3,914.64 is fish feed), which represents 45% of the total, annualized operating cost.

Table 2.5. Cash flow and financial results for the profit efficient treatment

Cash Flow	
Initial investment	R$ 91,225.95
Annual fixed cost	R$ 9,181.27
Annual variable cost	R$ 7,389.36
Total annual cost	R$ 16,570.63
Tilapia annual revenue	R$ 29,732.20
Lettuce annual revenue	R$ 2,978.40
Total annual revenue	R$ 32,710.60
Annual cash flow	R$ 16,139.98
Financial Results	
Internal Rate of Return - IRR (per year)	9.63%
Annual Interest Rate	6.00%
Net Present Value - NVP (R$)	15,830.52
Payback (Years)	7.60
Discounted Payback (Years)	9.23
Benefit/Cost	1.20
Discounted Benefit/Cost	1.13

To get the annual values for variable cost as well as for revenue values, it is assumed that each system produces throughout the year with a one-day interval between each cycle to allow for system repairs, cleaning etc. Therefore, the treatment considered in this analysis has a cycle of 29 days, or 12.17 harvests in a year (365 days in a year divided by 30, the period of the cycle plus the interval day). In addition, all the observed variable costs and outputs results for a single system were multiplied by 16, the number of aquaponics units in the experimental structure. This is a reasonable size of aquaponics system for a commercial producer (Engle, 2015). It was necessary to calculate long run financial results because, although each treatment was tested in only one aquaponics unit, all 16 units ran at the same time and the investment and fixed cost values are for the whole structure.

For this experiment, the revenue from juveniles is 10 times higher than revenue from lettuce, because in the treatment being evaluated, only nine lettuce units (for just one of the 16 aquaponics units and for only one cycle) was considered salable. The total annual revenue is R$ 32,710.60 resulting in an annual cash flow of R$ 16,139.98. Regarding the initial investment, some assets have lives of less than 10 years and they are replaced when wearing out. One asset (greenhouse infrastructure) has life greater than 10 years and no salvage value is considered. With the annual cash flow and an annual interest rate of 6%, a ten-year project is economically viable with an NPV of R$ 15,830.52 and IRR of 9.63%. The investment will be recovered, discounting at the interest rate, in 9.23 years and the total benefit is 1.13 larger than the total cost. This result may not be very attractive to investors since it takes almost the entire period of project to get payback and the return of investment is only 13% after 10 years.

The results presented in Table 2.5 are for the most profit efficient treatment, as most of the treatments were not presently economically viability. Treatments with early harvest presents lower levels of output which results in smaller revenues. Treatments with higher stocking density and feeding rates present larger operating costs and not enough output production to cover costs. Finally, treatments with a lower feeding rate are cost efficient, but they present smaller revenue since the input is fundamental for the fish and plant growth.

2.5 Conclusions

An experimental study of the productivity of an aquaponics system was conducted at UNESP's (Sao Paulo State University) experimental aquaponics facility. Four different levels of initial fingerling stocking density0020and four feeding rates relative to the manufacturer's recommendations were measured in a 30-day experiment. Inputs were measured throughout the 30-day production period, and outputs were measured or estimated during the last 10 days of experiment. A series of non-parametric efficiency analysis and tests were performed to determine which treatments had the potential to be technically efficient. The results show that treatments with higher feeding rates levels are generally not efficient. Treatments with early harvest are also found to be less efficient, in general, than treatments that allow more time for the output growth.

Using regional average prices, the treatment with harvest on the 29th day, density of 250 (fish/m^3) and feeding at the manufacturer recommended rate is the most efficient, i.e., with the highest return above variable cost. Sensitivity analysis of this treatment showed that the best treatment is somewhat sensitive to the level of prices of juvenile fish and lettuce output. A complete financial analysis was done with this treatment and the results suggest that it is economically viable in a 10-year project period, though different assumptions on the cost of land, wages, water, and energy may change the economic viability of this system in a non-experimental situation.

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CHAPTER 3. CONSUMER WILLINGNESS TO PAY FOR ATTRIBUTES OF FISH FILLETS IN BRAZIL

3.1 Introduction

There is potential for growth and development of aquaculture markets in Brazil due to a deficit in the fisheries trade balance, which has increased in recent years due to increased imports (see Figure 3.1). The recent growth in domestic fish consumption, estimated at 4 kg per capita per year in 2005 and at 14.5 kg in 2013 (Scorvo Filho, 2014), is explained not only by the increase in national farmed fish production, but also by imports mainly from Norway, China, and Chile (Flores and Pedroza Filho, 2014).

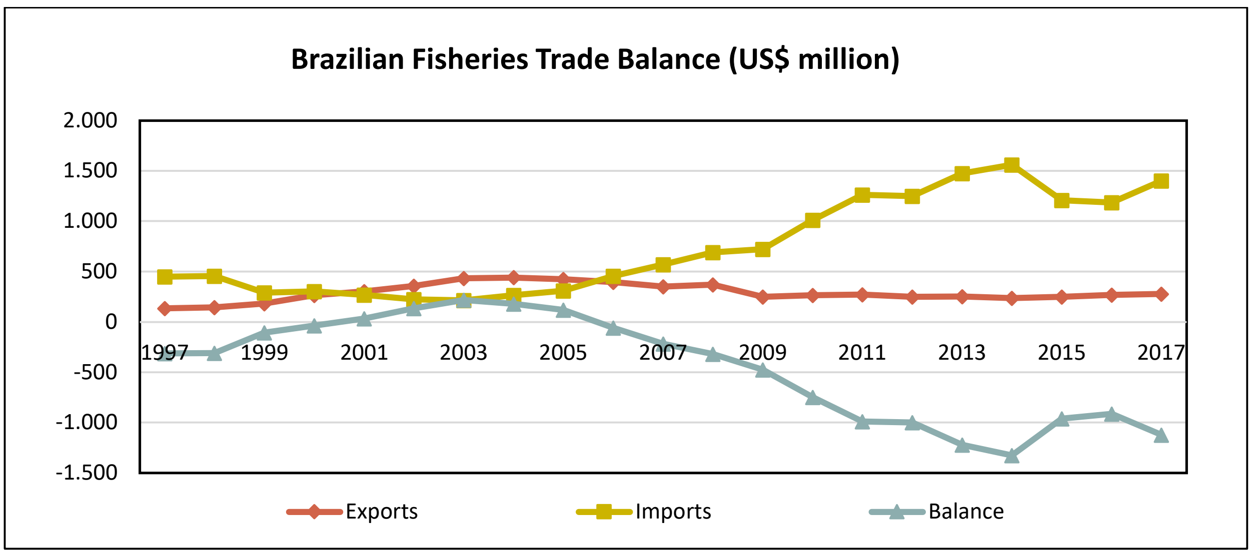

Figure 3.1. Fisheries trade balance (US$ million) – 1997-2017

Source: Brazilian Ministry of Fisheries and Aquaculture and Ministry of Industry, Foreign Trade and Services.

Understanding preferences for fish products in Brazilian markets is essential to inform the development of fish production and associated processing and retailing of fish products. However, presently data on Brazilian consumers' knowledge of the fish market and preferences for various product characteristics is limited. Past studies have worked with meat demand for Brazilian consumers, but there are few studies on seafood demand (Hoffmann, 2007; Carvalho et al., 2008;

Carbonari and Silva, 2012). Santana and Ribeiro (2008) found inelastic seafood demand, with fish being a complementary good for chicken and beef, and a substitute good for pork. Lopes et al. (2016) studied the factors that influence fish consumption for different regions in Brazil by interviewing more than one thousand people and found that most of the population prefers beef and poultry over fish. In addition, they found low yet increasing seafood consumption among the respondents, which they posited was mainly due to a lack of seafood products and a low level of information on the benefits of seafood consumption. There are some dated demand studies for seafood focused on specific regions in Brazil (Teixeira et al., 2006; Almeida et al., 2003). Using a very large survey of families' budgets, Sonoda et al. (2012) conducted a study on how consumption of seafood differs between the North and South regions in Brazil. Consumers with higher income levels from the South region buy seafood in supermarkets, but in the North, they tended to buy from farmers' markets and small fish stores. Pincinato and Gasalla (2010) tested the hypothesis that the demand price for seafood is elastic using time-series data from the Sao Paulo city seafood wholesale market from 1968 to 2007. The authors failed to reject the hypothesis that demand for seafood is elastic for most species analyzed.

There are no relevant economic studies in Brazil of the impact of variables such as species, processed form (fresh/frozen), and fish knowledge on consumers' fish selections. This essay is the first study to analyze the impact of factors like product price, consumers' demographics, and product attributes such as species and processing of fish in the Brazilian market for tilapia and tambaqui, the two most important farmed fish species in Brazil (Carvalho Filho, 2018; Flores and Pedroza Filho, 2019). This study provides important product and market information for managers of fish farms and the seafood processing industry for both species through testing the following hypotheses:

- Brazilian consumers exhibit heterogeneous preferences for fish species and processed forms;
- Willingness to pay for species and product form vary across regions of Brazil; and
- Fish knowledge has an impact on the stated preferences/demand of consumers.

3.2 Methodology

Past studies have employed varying methodologies to explain what factors influence the demand for seafood in different parts of the world (Asche et al., 2001; Ligeon et al., 2007; Sakai et al., 2010). An example of the impact of price on fish consumption is a study conducted by Dey et al. (2011), in which the authors used the Almost Ideal Demand System (AIDS) model with a broad source of consumer data from the WorldFish Center and the Bureau of Socioeconomic Research and Training of the Bangladesh Agriculture University to estimate the coefficients for six groups of fish species in the Bangladeshi market. Studying consumer choices of fresh fish in the West Mediterranean area, it was found that the residents preferred to buy fish in traditional retail markets and were willing to pay a premium for local products of good quality (Morales-Nin et al., 2013).

In the present analysis, random utility theory is used to model consumer demand for the fish attributes of species and fillet form. The depiction presented below follows McKendree et al. (2013), who used an attribute-based method based on Lancastrian consumer theory (Lancaster, 1966). Fundamentally, the utility of a product can be separated into different utilities for their attributes. Since the researcher has incomplete information, a consumer's utility is a random variable (Manski, 1977). Therefore, the model is derived from utility-maximization behavior where alternative j is selected from a set of J possibilities in choice scenario k (the alternatives/pricing that confront the consumer). Utility is specified as:

$$U_{jk} = V_{jk} + \varepsilon_{jk} \ , \tag{14}$$

where V_{jk} is the deterministic part of the utility according to the attributes of alternative j and ε_{jk} is a random term that is independent and identically distributed (iid) Type 1 Gumbel distributed over all alternatives and choice scenarios.

The decision-maker chooses alternative j if and only if $U_{jk} > U_{ik}, \forall\, j \neq i$. The probability of selecting j is $Prob(V_{jk} + \varepsilon_{jk} > V_{ik} + \varepsilon_{ik}; \forall\, j \neq i;\ \forall\, i \in D\,)$, where D is the total set of alternatives available to the participant (Boxall and Adamowicz, 2002). Adamowicz and Swait (2011) show that, since the random term ε_{jk} is iid across the j alternatives with an extreme value distribution, the probability is given by the standard logit:

$$Prob(j \ is \ chosen) = \frac{e^{\theta V_{jk}}}{\sum_i e^{\theta V_{ik}}} \ , \tag{15}$$

where θ is a scale parameter, which is inversely related to the variance of the error term. If the deterministic part is assumed to be linear in parameters, it can be expressed as:

$$V_{jk} = \beta_1 x_{jk1} + \beta_2 x_{jk2} + \cdots + \beta_m x_{jkm} \ , \quad (16)$$

where x_{jkm} is the m-th attribute for alternative j, and β are parameters associated with the attributes. Equations (15) and (16) describe a multinomial logit model, but poor estimates will result if individuals have heterogeneous preferences for product attributes since the model assumes homogeneous preferences (Olynk et al., 2010). Thus, the random parameters logit (RPL – also known as mixed logit) model is used to allow for heterogeneity in respondents' preferences. In this model, an individual's preference for fish attributes is allowed to deviate from the population mean, which means that the coefficient vector for individual *n* is $\beta_n = \bar{\beta} + \sigma\mu_n$, where $\bar{\beta}$ is the population mean, σ is a diagonal matrix of coefficient standard deviations and μ_n is a vector of independent standard normal deviates (Lusk et al., 2003). The RPL allows estimation of the heterogeneity in consumer preferences across the evaluated attributes directly. The random utility of individual *n* is:

$$U_{njk} = v_{njk} + [u_{nj} + \varepsilon_{njk}] \ , \quad (17)$$

where v_{njk} is the systematic part of the utility function, u_{nj} is an error that is distributed normally over individuals and alternatives (but not choice scenarios), and ε_{njk} is the random term that is iid over all consumers, alternatives, and choice scenarios (Olynk et al., 2010).

The parameters are estimated in a model for demand for fish fillets from tilapia or tambaqui, fresh or frozen, and the price. The model for the systematic part is:

$$v_{jk} = \beta_0 OptOut_k + \beta_1 Price_{jk} + \beta_2 tilapia_{jk} + \beta_3 fresh_{jk} \ , \quad (18)$$

where j denotes the alternative, k denotes the choice scenario, $Price$ is the price of the fillet, and $OptOut$ is a constant that describes the disutility of not having the fish product in the consumer's choice scenario (Johnson et al., 2000). The variable $tilapia$ is an effects-coded term which represents the species choice, and $fresh$ is an effects-coded term which represents the choice between fresh and frozen forms. In effects coding, instead of a dummy variable that values 0 or 1, the attributes take a value of 1 when applicable, a value of -1 when the base category applies, and zero otherwise (Tonsor et al., 2009). Thus, the "left out" category is not incorporated into the intercept as in traditional dummy variable estimation (Lusk et al., 2003). Effects coding was used instead of dummy variables to avoid confounding effects of attribute levels with the opting-out option (when the consumer does not choose either of the fish options presented).

Estimating the parameters of the model is straightforward using maximum likelihood. The willingness-to-pay (WTP) for an attribute is:

$$WTP_m = -2 \times \left(\frac{\beta_m}{\beta_1}\right), \tag{19}$$

where β_m represents the coefficient on the attribute m, and β_1 is the coefficient on price. Following Lusk et al. (2003), the numerator is multiplied by 2 due to effects coding.

To allow the analysis of variability in the WTP estimations, this essay uses parametric bootstrapping to calculate 95% confidence intervals for coefficients. Using the variance-covariance matrix and means estimated from the RPL, simulations of WTP estimate observations were drawn for each variable from a normal distribution a thousand times (Krinsky and Robb, 1986). In addition, a complete combinatorial method (Poe et al., 2005) was used to determine if the WTP distribution calculated was different for one region compared to another.

3.3 Data

The data to estimate the parameters presented in the methodology section were collected from 1,352 fish consumer interviews administered in person at seafood counters in supermarkets of a representative city for each of the five Brazilian Regions. The selected cities were Manaus, Curitiba, Sao Paulo, Recife, and Brasilia, representing the North, South, Southeast, Northeast, and Midwest regions, respectively. The interviews were administered in February 2019 in supermarkets in at least three different neighborhoods in each city, reaching populations with different income levels. The administered questionnaire contains questions about sociodemographic attributes, fish consumption, fish knowledge and the choice experiment for tilapia and tambaqui fillets. The complete questionnaire used is presented in Appendix B.

To determine choice scenarios, an experimental design was developed using the SAS OPTEX maximizing D-efficiency[3] (Lusk and Norwood, 2005) considering two fish species (tilapia and tambaqui), two product forms (fresh and frozen) and four price levels for the fillet in kg (R$ 25, R$ 28, R$ 32 and R$ 35). The maximum D-efficiency was 85.51, resulting in 13 choice scenarios. However, four scenarios were disregarded, in keeping with the suggestion of Hensher and Barnard (1990) to remove choice sets that contribute no useful information (i.e. choices with the same attributes but higher prices do not need to be asked, since the consumer will prefer the same attribute at the lowest price) resulting in nine choice scenarios in the questionnaire. In addition to the two purchase options presented in each scenario, the consumer being interviewed had a choice of not purchasing either option, with is represented by the OptOut variable in equation (18).

The interviews were administered using tablet computers in front of the fish counter of each store with pictures of each choice presented on the tablet to consumers. To be selected to participate, customers had to indicate that someone in their family consumes fish. Before launching the country-wide data collection, a pretest of the questionnaire was administered in Piracicaba, a different city from the other five, to verify that the questions, the required survey time, and the planned approach would work in the actual retail supermarket data collection setting.

The results are presented by region, and Table 3.1 shows the summary statistics of the demographics for respondents. The distributions of age, income, and education are similar across the five regions. A high concentration of individuals between 31 and 60 years old, in the third level of family income, and with educational attainment of at least a high school level completed is observed. In addition, the total number of people and a child under 12 years old living in the household is also approximately the same in the five Brazilian regions. According to the Brazilian Institute of Geography and Statistics (IBGE) females comprise 51.5% of Brazilians. There is some noticeable variation by region of the proportion of respondents who were female, ranging from 43% in the South and North to 62% in the Northeast.

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[3] D-efficiency maximization can be thought of as minimization of the variance of coefficient estimates in a linear model. The criterion is scaled to range from 0 to 100, where a balanced orthogonal design with optimum efficiency corresponds to 100 (Kuhfeld et al., 1994).

Table 3.1. Demographics results for subjects participating in the consumer survey

	South (n=300)	Southeast (n=300)	Midwest (n=212)	Northeast (n=300)	North (n=240)
Percentage (%) of survey respondents					
Gender					
Female	42.6	60.5	46.2	62.0	42.9
Age					
Under 21	4.0	2.3	2.4	2.7	2.5
21-30	12.7	8.7	13.2	16.0	16.7
31-40	22.7	17.3	18.4	24.0	20.0
41-50	22.7	23.3	20.8	21.0	19.2
51-60	23.7	24.7	22.2	21.3	18.3
61-70	9.0	17.0	16.5	9.3	15.8
Above 70	5.3	6.7	6.6	5.7	7.5
Household income					
E (Less than R$ 1254)	18.0	14.8	13.1	15.2	15.0
D (R$ 1255 - R$ 2004)	14.1	14.4	17.7	12.4	16.3
C (R$ 2005 - R$ 8640)	44.4	46.6	48.0	54.0	42.5
B (R$ 8641 - R$ 11261)	14.8	17.2	15.2	14.0	21.0
A (More than R$ 11262)	8.8	6.9	6.1	4.4	5.2
Education					
No formal school	0.3	0.0	0.0	0.0	0.4
Primary incomplete	5.0	4.1	5.9	4.8	5.1
Primary complete	8.1	5.1	7.4	4.8	5.1
High school incomplete	2.4	3.4	4.4	3.5	3.0
High school complete	27.5	28.0	18.2	27.7	23.7
Bachelor incomplete	10.1	15.4	13.3	13.2	13.6
Bachelor complete	31.2	28.3	34.0	29.1	30.1
Graduate	15.4	15.7	16.8	17.0	19.1
People at home					
Average (everyone)	3.3	3.4	3.3	3.4	3.3
Average (below 12 years old)	0.4	0.5	0.5	0.4	0.4

3.4 Results

3.4.1 Fish consumption patterns

In addition to assessing the demographics for consumers participating in the survey, it is important to analyze fish consumption characteristics and fish knowledge before presenting the results for the choice experiment and the RPL model. Table 3.2 displays statistics of fish consumption for survey respondents. In general, there does not appear to be a strong preference for fish from freshwater or saltwater, although there are differences among regions. Since aquaculture in Brazil is mainly freshwater, this result suggests aquaculture could be an important source of freshwater fish. The Midwest region shows the highest preference for freshwater fish, which is expected because it is the only region of Brazil without an ocean coast. However overall, survey respondents showed higher preference for wild-caught fish (over farmed fish) in every region of the country. This result is an indication that promoting aquaculture is an important strategy for increasing farmed fish consumption, because most of the preference for wild-caught fish is due to a lack of knowledge about the production process (Davidson et al., 2012).

Table 3.2. Fish consumption characteristics for subjects participating in the survey

	South (n=300)	Southeast (n=300)	Midwest (n=212)	Northeast (n=300)	North (n=240)
Percentage (%) of survey respondents					
Fresh water-sea preference					
Fresh water	30.7	26.9	31.6	25.4	25.0
Sea / Saltwater	29.4	31.3	24.3	29.2	34.3
Indifferent	39.9	41.8	44.2	45.4	40.7
Fishery-aquaculture preference					
Farmed	6.1	7.5	10.2	6.9	6.4
Wild-caught	50.9	48.6	48.3	53.6	48.9
Indifferent	43.0	43.9	41.5	39.5	44.7
Where consumers bought fish					
Supermarket	78.0	77.3	76.9	80.7	80.8
Fish store	18.3	22.3	20.8	17.3	15.0
Butcher shop	1.3	0.3	0.5	1.0	0.0
Farmers' market	13.7	14.0	15.1	12.7	15.4
City market	5.0	7.0	7.6	6.7	5.4
Direct fishers/farmers	4.3	6.0	5.2	5.3	5.8
Other	6.7	5.7	6.1	4.0	5.0
Forms of fish purchased					
Fillet	83.6	87.8	83.9	85.3	83.9
Strips	26.6	28.6	26.8	28.1	30.6
Chunk	61.0	64.5	64.9	64.4	65.5
Whole fish	66.3	61.1	66.3	67.1	63.4
Canned	63.8	57.7	61.0	58.4	56.2
Fresh	93.8	93.2	95.1	95.9	92.8
Frozen	58.6	62.7	63.9	63.6	58.5
Salted	58.9	57.5	66.8	62.2	61.3
Cooked	69.6	68.7	74.9	70.1	66.8
Family expenses (R$/month)					
On food (average)	1194.4	1161.0	1209.9	1231.4	1199.4
On fish (average)	161.7	145.0	154.8	174.7	159.4

More than three quarters of respondents in each region buy fish regularly in supermarkets. Besides supermarkets, specialty fish stores and famers' markets are alternative places where people also report buying fish. Fish processors thus have diverse market outlets for selling fish products. Regarding the forms of fish that are purchased regularly, fillet and fresh are the most popular in the country, indicated by 85% and 94%, respectively. Table 3.2 summarizes monthly expenditures on fish and finds that they are similar among regions in Brazil, with spending of R$ 1200 for all kinds of food and about R$ 160 for fish. On average, respondents (whom are all fish consumers) spent about 13% of their food budget on fish.

3.4.2 Knowledge about fish species

Table 3.3 presents summary statistics for questions that assess the fish knowledge of the respondents. The first two parts of the table show the percentage of consumers who can correctly identify pictures of some of the important fish species in the Brazilian market. For whole fish pictures, consumers are more familiar with tilapia, pintado, and salmon, species that are traditionally found in Brazilian markets. Pirarucu and tambaqui are native species from Amazon Rivers, and the population of North Region, that has most of its area in the Amazon Forest, is more familiar to them. Results for both species had a higher percentage of correct identification for the North Region than other regions. Consumer familiarity with some important fish species presents opportunities to explore additional species for aquaculture in Brazil. Pirarucu and tambaqui are less often correctly identified by consumers from fillet pictures. Besides being native species from the North Region, fillet forms of both species are not traditional, and some processing facilities are just starting to supply them.

Table 3.3. Fish knowledge of subjects participating in the survey

	South (n=300)	**Southeast (n=300)**	**Midwest (n=212)**	**Northeast (n=300)**	**North (n=240)**
Percentage (%) of survey respondents					
Is able to identify the species in a picture					
Tambaqui	45.6	47.5	48.5	50.5	52.3
Tilapia	63.8	60.8	64.3	62.3	59.8
Pintado (catfish)	67.5	66.9	70.5	70.4	66.0
Pirarucu	43.0	41.2	42.2	47.3	49.6
Salmon	69.0	58.5	53.1	59.1	57.6
Is able to identify the fillet in a picture					
Tambaqui	41.4	34.6	39.6	42.4	39.4
Tilapia	66.6	64.8	60.9	66.2	64.8
Pirarucu	52.2	47.8	46.9	54.6	49.2
Salmon	77.1	77.3	73.0	80.8	76.2
Knows if it is farmed or wild-caught					
Tilapia	43.5	42.7	45.4	42.4	46.4
Tambaqui	16.2	20.2	20.0	27.4	22.7
Salmon	9.3	12.7	12.7	13.9	11.1
Sardine	51.2	53.5	49.8	57.6	52.3
Pintado (catfish)	11.1	11.0	12.8	4.5	11.1
Saint Peter vs tilapia					
Knows that Saint Peter fillet is tilapia	12.1	11.0	9.8	8.7	9.8

Knowledge about species that are farmed or wild-caught was also assessed. In general, respondents knew that tilapia is farmed, and that sardine is wild-caught. Other species can come from both sources of production, and consumers were generally unsure about how they are sourced. Saint Peter fillet was a name created as a market strategy for tilapia fillet for some states in the South and Southeast Regions (Kubitza, 2010). The idea was that consumers would prefer a different product with an English name, which was successful to the extent that some consumers said they prefer the Saint Peter fillet. The results show that about 10% of respondents know that Saint Peter and tilapia are the same; more consumers were aware that the two names refer to the same fish in the South and Southeast regions where this market strategy was used. Fish knowledge has an impact on consumers' preferences. Consumers tend to prefer consuming fish species that they can identify and know how they are produced.

3.4.3 Results from econometric analysis

The coefficients estimated in the RPL model and the mean WTP estimates are presented in Table 3.4. All parameters in the model were found to be statistically significant. The coefficients were used to calculate the WTP estimates and associated confidence intervals. Except for the price variable, other explanatory variables were specified to vary normally across the sample. For all regions except Midwest, the random parameters have statistically significant standard deviations as well. The mean WTP estimates cannot be interpreted as being representative of the whole sample, since the model presented statistically significant diagonal elements in the Cholesky matrix, which indicates the presence of preference heterogeneity (McKendree et al., 2013). Results from the combinatorial method proposed by Poe et al. (2005) show that, for each attribute, the WTP estimates did not differ across regions.

Table 3.4. Parameters from correlated RPL and mean WTP estimates for tilapia and tambaqui fillet for five Brazilian Regions

	Variable	Coefficient (standard error)	Standard deviation (standard error)	Mean WTP (R$) [confidence interval]
South	OptOut	-8.73302***	5.24055***	-41.12
		(0.80158)	(0.45008)	[-45.42 , -37.53]
	Tilapia	1.17864***	2.91891***	11.10
		(0.18918)	(0.26404)	[7.28 , 15.61]
	Fresh	2.82335***	2.49630***	26.59
		(0.22967)	(0.22162)	[21.63 , 33.03]
	Price	-0.21239***		
		(0.02118)		
Southeast	OptOut	-6.30680***	6.23263***	-42.24
		(0.72321)	(0.67232)	[-48.68 , -37.21]
	Tilapia	1.19012***	2.59268***	15.94
		(0.18550)	(0.18181)	[10.63 , 22.95]
	Fresh	2.47430***	2.12634***	33.14
		(0.22380)	(0.18322)	[24.89 , 44.91]
	Price	-0.14932***		
		(0.01964)		
Midwest	OptOut	-3.76346***	0.11309	-33.51
		(0.54378)	(0.22723)	[-35.80 , -31.59]
	Tilapia	0.89627***	2.10174	15.96
		(0.18008)	(0.19162)	[9.29 , 25.68]
	Fresh	1.58539***	1.12601***	28.23
		(0.12287)	(0.11135)	[24.54 , 40.71]
	Price	-0.11231***		
		(0.01758)		
Northeast	Optout	-9.97463***	5.40616***	-43.15
		(0.86679)	(0.44401)	[-48.20 , -38.74]
	Tilapia	0.75772***	3.02082***	6.56
		(0.17830)	(0.25330)	[3.38 , 10.13]
	Fresh	2.54543***	1.81019***	22.02
		(0.18911)	(0.17221)	[18.16 , 27.08]
	Price	-0.23118***		
		(0.02212)		
North	OptOut	-8.93798***	6.17997***	-43.38
		(1.00014)	(0.69095)	[-49.80 , -38.74]
	Tilapia	1.04372***	4.49560***	10.13
		(0.27779)	(0.41376)	[4.84 , 16.49]
	Fresh	2.99109***	2.62738***	29.04
		(0.30071)	(0.27123)	[22.63 , 38.29]
	Price	-0.20602***		
		(0.02629)		

*Note: *** indicates significance at the 1% level.*

Consumers are, on average, willing to pay more for tilapia and fresh fillets than tambaqui or frozen fish. For tilapia, the lowest WTP was found in Northeast Region where consumers are willing to pay a premium of R$ 6.56 to purchase one kg of tilapia instead of tambaqui on average. On the other hand, Southeast and Midwest have the highest WTP for premium tilapia of almost R$ 16. Overall the results indicate a preference for tilapia especially in regions where tambaqui does not have a mature market.

Freshness appears to be the most important attribute for consumers in Brazil. In the Southeast, for example, consumers are willing to pay a premium for fresh fillet above the average price of the choice experiment that is R$ 30.00. Even in the Northeast where the WTP is lowest for freshness, the premium value of R$ 22.02 per kg represents a high preference for this attribute. According to IBGE, the monthly per capita income in 2018 in the state where Recife is the capital (Northeast) was R$ 871, and for Sao Paulo (Southeast) it was R$ 1,898. The result suggests the possibility that freshness may be more highly valued by consumers with higher income.

Table 3.5 presents percentiles of the distribution of estimated individual-specific WTP for attributes studied. Although the respondents of the survey prefer tilapia on average, more than one quarter of consumers had a negative WTP for tilapia. On the other hand, in the Midwest and North regions, more than 10% of consumers would pay more than R$ 60 to have tilapia instead of tambaqui. The preference for freshness is even stronger, and in the Northeast and Midwest regions more than 95% had a positive estimated individual-level WTP premium for the fresh variable. In the South, Southeast, and North regions, three quarters of consumers were willing to pay more than R$ 40 to have the fresh product (rather than frozen).

Table 3.5. Percentiles of OptOut, tilapia and fresh WTP (R$/kg) distribution per Brazilian region

	Percentile						
	5%	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**
South							
OptOut WTP	-64.19	-62.72	-60.55	-43.01	-30.17	-8.02	6.48
Tilapia WTP	-32.31	-25.16	-0.38	10.52	29.51	43.78	43.92
Fresh WTP	-1.65	4.24	13.84	23.63	41.82	56.75	56.95
Southeast							
OptOut WTP	-86.12	-80.58	-77.36	-60.75	-30.10	-0.10	29.88
Tilapia WTP	-51.77	-40.78	-3.01	19.92	35.38	52.85	56.62
Fresh WTP	-1.69	2.59	16.90	32.06	47.25	67.62	68.35
Midwest							
OptOut WTP	-35.14	-34.81	-34.09	-33.60	-32.95	-32.13	-32.12
Tilapia WTP	-44.48	-32.22	-5.52	12.42	36.76	67.21	67.41
Fresh WTP	2.30	6.09	15.82	26.84	38.95	51.78	53.57
Northeast							
OptOut WTP	-62.97	-61.08	-59.99	-52.23	-31.02	-12.11	-2.33
Tilapia WTP	-41.17	-31.33	-7.59	5.66	24.49	39.24	39.40
Fresh WTP	1.34	6.63	15.12	21.56	31.41	41.47	42.65
North							
OptOut WTP	-73.67	-69.83	-65.74	-47.00	-30.57	-2.89	10.44
Tilapia WTP	-61.49	-48.99	-11.30	14.51	47.27	60.47	60.92
Fresh WTP	-0.66	6.04	15.22	25.75	44.67	58.22	61.98

3.4.4 WTP across respondents with varying characteristics

For a better understanding of the consumers with higher or lower preferences, sociodemographic, fish consumption, and fish knowledge variables were crossed with purchasing behavior from the choice experiment. For each region, Table 3.6 highlights some characteristics that are different from the average WTP for the two extremes in the distribution (10% of consumers that prefer more and the 10% that prefer less of each attribute). A more complete list of characteristics different from the average is found in Appendix C.

Table 3.6. Highlights of sociodemographic, fish consumption and fish knowledge variables for consumers with higher and lower preferences on fish attributes

Tilapia - lower than 10th percentile	Tilapia - higher than 90th percentile
South	
More able to identify the whole tambaqui picture (93%)	More aware that Saint Peter and tilapia fillet are the same (29%)
Higher average monthly consumption of fish (R$ 251)	Purchase more fish fillet at least occasionally (93%)
Southeast	
More able to identify the whole tambaqui picture (89%)	More aware that Saint Peter and tilapia fillet are the same (17%)
Higher average monthly consumption of fish (R$ 210)	Purchase more fish fillet at least occasionally (93%)
Midwest	
More able to identify the whole tambaqui picture (86%)	Higher presence in income classes D and E (45%)
Higher average monthly consumption of fish (R$ 289)	Purchase more fish fillet at least occasionally (95%)
Northeast	
More able to identify the whole tambaqui picture (93%)	Lower average monthly consumption of fish (R$ 111)
Purchase more whole fish at least occasionally (97%)	Purchase more fish fillet at least occasionally (96%)
North	
More able to identify the whole tambaqui picture (96%)	Fewer children at home on average (0.25)
Purchase more whole fish at least occasionally (91%)	Prefer more farmed fish (13%)

Fresh - lower than 10th percentile	Fresh – higher than 90th percentile
South	
Fewer children at home on average (0.25)	More able to identify the tilapia fillet picture (80%)
Buy more in supermarkets (90%)	Higher presence in income classes D and E (41%)
Southeast	
Fewer children at home on average (0.29)	Higher average monthly consumption on fish (R$ 199)
Buy less in farmers markets (0%)	Lower presence in income classes A and B (11%)
Midwest	
Prefer more farmed fish (18%)	Prefer more wild-caught fish (58%)
Higher presence in income classes A and B (48%)	Lower presence in income classes A and B (6%)
Northeast	
Prefer less freshwater fish (13%)	More able to identify the tilapia fillet picture (83%)
Higher presence in graduate educational level (40%)	Higher presence in income classes D and E (45%)
North	
More consumers are older than 40 years old (54%)	More able to identify the tilapia fillet picture (92%)
Prefer more sea/saltwater fish (50%)	Purchase more fish fillet at least occasionally (96%)

Table 3.6 shows that consumers who prefer tambaqui are more able to identify this species in the questionnaire. About half of subjects (from the entire sample) identified tambaqui in a picture (Table 3.3), whereas about 86% of consumers that preferred tambaqui knew how to identify it, depending on the region. This result is an indication that knowledge about tambaqui is important to its preference. Tilapia is better known than tambaqui for most of Brazilian consumers and some consumers may have chosen it in the choice experiment because they have not tried tambaqui before. Another different characteristic that corroborates these findings is that consumers that prefer tambaqui have higher consumption of fish (spend more on fish and buy more whole fish) in the observed sample. Food industry managers, and in particular those seeking to develop the tambaqui marketplace in various regions of Brazil, may seek to provide additional consumer educational materials at fish counters or seafood markets to inform shoppers of options available.

Consumers that prefer more tilapia in the South and Southeast regions more often (correctly) reported that a Saint Peter fillet is a tilapia fillet. These regions are where this marketing strategy was applied, and knowing that a higher quality fillet like Saint Peter is tilapia, helps when making a species choice. In addition, in most regions, consumers with a higher purchase frequency of fish fillet also prefer tilapia fillet, the most common fish fillet in Brazilian markets. This suggests the importance of product availability in fish retail outlets.

A lower preference for freshness is related with characteristics like lower number of children at home, higher income level, higher educational level, and older age. Consumers with lower WTP for fresh buy more in supermarkets and less in farmers' markets. Those demographic characteristics are associated with consumers that prefer more convenience in their food preparation and frozen fish is convenient. In addition, consumers with a higher preference for fresh fish are more able to identify the tilapia fillet picture in the questionnaire, which shows a correlation between fish knowledge and preference for fresh fillet.

3.5 Conclusions

This study estimated the WTP for fillet of the two most important farmed fish species in Brazil, tilapia and tambaqui. However, consumer familiarity with other important fish species presents opportunities to explore additional species for aquaculture in Brazil. Results were analyzed for consumers across five national regions in Brazil and by key shopper characteristics.

Since individuals have heterogeneous preferences for product attributes, the RPL model was used through a choice experiment conducted in person in supermarkets in the main city of each region. The estimated distributions of WTP for fillets by species (tilapia and tambaqui) and form (fresh versus frozen) were not statistically different across regions.

On average, Brazilian fish consumers prefer tilapia to tambaqui and fresh to frozen fillets. Results suggest strong relationships between fish knowledge and species selection preferences, indicating potential room for communication and/or marketing to improve shopper awareness of fish availability. The preference for freshness is very strong, relative to frozen fillets, with almost all respondents in the survey indicating a positive WTP for fresh. The strong preference for fresh versus frozen product points towards the potential for supply chain management to adapt to enable supermarkets to offer fresh product to those consumers demanding it. Consumers who purchased fish fillet frequently preferred tilapia, suggesting the importance of product availability in retail fish outlets.

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CHAPTER 4. SPATIAL EQUILIBRIUM ANALYSIS FOR FISH SUPPLY AND DEMAND IN BRAZIL

4.1 Introduction

Analyzing the relationships in aquaculture is important for understanding the synergies within the supply chain, how demand and supply agents interact, and the effects of specific changes on the sector as a whole, as well as on the regional distribution of production and consumption. Although existing literature does not present an analysis of the aquaculture supply chain, several studies have examined equilibrium models for other commodities. For example, Havlík et al. (2014) studied how livestock system transitions impact climate change mitigation using a spatial equilibrium model determining optimal landing and resources allocation by maximizing the sum of consumer and producer surplus. In another example, Mwanaumo et al. (1997) focused a spatial equilibrium analysis on evaluation of the effects of maize marketing policy reforms in Zambia. McCarl and Spreen (1980), also discuss the usefulness of mathematical programming sector models in which both price and quantity are endogenous variables for policy analysis.

Different methodologies for formulating economic equilibrium models have been discussed in the literature; spatial competition (Harker, 1986), spatial price equilibrium (Tobin, 1988), multimarket setting (Alston, 1991) and, nonlinear mixed complementarity problems (Dirkse and Ferris, 1995) where the authors also present a spatial price equilibrium model similar to what is used in this research. However, the model used by Dirkse and Ferris (1995) focuses on a Nash equilibrium for determining outcomes with imperfect competition and is different from the approach presented below. One advantage of the mixed complementarity approach is that it does not impose the requirement of integrability, or symmetry of the demand cross-price effects, as is typically required with optimization formulations. When the empirical evidence suggests demand asymmetry, formulation as a complementarity problem obviates the need to distort the demand system with an imposed symmetry assumption.

The objective of this essay is to assess the impact of policies and expected changes in the economic environment on the spatially disaggregated supply chain for the two main fish farming species in Brazil, tilapia and tambaqui, using a partial equilibrium model. This approach allows evaluation of the impact of factors such as government incentives (e.g., subsides to reduce fish feed prices), international oil price shocks (changes in the cost of transportation), and projected increases in consumers' income on the regional pattern of production and final consumption. Brazilian policy makers need to be cognizant of these potential impacts in order to design policy that will support the growing aquaculture sector.

4.2 Methodology

A spatial equilibrium model for the farmed fish supply chain in Brazil, with model scope that begins with farmers, includes the processing sector, the transportation sector, retailers and final consumers, is developed. Tambaqui is representative of all Brazilian "round" fish[4] (tambaqui, pacu, pirapitinga and their hybrid combinations), because they are very similar economically (farming system, processing, pricing and consumers' familiarity). The final fish products to be consumed in the model can be fresh or frozen and whole, cleaned fish or fish fillets, resulting in four possible final forms for each species.

For each sector of the economy, the country is divided into regions according to the concentration of producers for the production regions and population centers for the demand regions. Generally, processing facilities are located near producers; so, these facilities are treated as collocated. A transportation sector moves processed fish from production regions to demand regions. Demand regions are indexed by j, and supply regions are indexed by i. Fish species (tilapia and tambaqui) is indexed by s, and form (fresh/frozen and whole/fillet) is indexed by k. Model variables are:

- f_{is}: annual production farmed in region i of species s (tons of unprocessed fish);
- p_{isk}: annual production processed in region i of species s into form k (tons of processed fish);
- t_{ijsk}: annual flow of fish in form k of species s from supply region i to demand region j (tons of processed fish);
- d_{jks}: annual demand in region j per species s in form k (tons of processed fish);
- z_{is}: fish farmer selling price in region i of species s (R$/tons of unprocessed fish);

[4] The group of round fish includes several Amazonian species of the Colossoma and Piaractus genus.

- g_{isk}: processor selling price in region *i* of species *s* into form *k* (R$/tons of processed fish); and
- b_{jks}: demand price in region *j* for species *s* in form *k* (R$/tons of processed fish).

The parameters are:

- c_{is}: cost (R$) per ton to produce species *s* in region *i*;
- a_{sk}: tons of unprocessed fish of species *s* required to produce one ton of processed fish of species *s* in form *k*;
- h_{isk}: cost (R$) per ton to process species *s* into form *k* in region *i*;
- r_{ijsk}: transport cost (R$) per ton of processed fish species *s* in form *k* shipped from supply region *i* and sold in demand region *j*; and
- δ_{jsk}: retailer gross margin (R$) per ton for species *s* in form *k* in region *j*.

The linear demand function is described as:

$$\boldsymbol{d}_j = \boldsymbol{\alpha}_j + \boldsymbol{\beta}_j \boldsymbol{b}_j + w_j \boldsymbol{\eta}_j \quad , \tag{20}$$

where: $\boldsymbol{d}_j$ is a vector (*ks* x 1) with elements d_{jks}, $\boldsymbol{\alpha}_j$ is a vector (*ks* x 1) of intercepts, $\boldsymbol{b}_j$ is a vector (*ks* x 1) with elements b_{jks}, $\boldsymbol{\beta}_j$ is a matrix (*ks* x *ks*) of price coefficients, w_j is the average family income (R$/month) in region *j* and $\boldsymbol{\eta}_j$ is a vector (*ks* x 1) of income coefficients. The corresponding inverse demand function is:

$$\boldsymbol{b}_j = \boldsymbol{\beta}_j^{-1}[\boldsymbol{d}_j - \boldsymbol{\alpha}_j - w_j \boldsymbol{\eta}_j] \quad . \tag{21}$$

If the demand relationship (21) satisfies an integrability condition (i.e., symmetry of the matrices $\boldsymbol{\beta}_j$), then the equilibrium problem may be formulated as a nonlinear program per Takayama and Judge (1964) that uses an objective of maximizing net social payoff (NSP). Samuelson (1952) interprets the net social payoff as the area between the demand curve and supply curves up to the point of equilibrium quantity. Whether the integrability condition is satisfied is an empirical question, and in the work presented here, this condition is not satisfied.

To accommodate the asymmetry of demand, the problem is formulated as a mixed complementary program (MCP) (Ferris et al., 1998) that allows the use of an asymmetric $\boldsymbol{\beta}_j$. This is similar to the system of Karoush-Kuhn-Tucker conditions, except that the second derivatives corresponding to the Hessian matrix in the integrable case are replaced by the asymmetric matrices $\boldsymbol{\beta}_j$. Using ⊥ to represent complementary slackness, the equilibrium conditions may be written as a nonlinear complementary problem. The relationships in the model are:

$$\sum_i^8 t_{ijks} \geq d_{jks} \;\perp\; b_{jks} \geq 0 \quad \text{for all k = 1, …,4; s = 1,2 and j = 1, …,5;} \quad (22)$$

$$p_{isk} \geq \sum_j^5 t_{ijks} \;\perp\; g_{isk} \geq 0 \quad \text{for all i = 1, …,8; k = 1, …,4 and s = 1,2;} \quad (23)$$

$$f_{is} \geq \sum_k^4 a_{sk} \times p_{isk} \;\perp\; z_{is} \geq 0 \quad \text{for all i = 1, …,8 and s = 1,2;} \quad (24)$$

$$b_{jks} \geq \boldsymbol{\beta}_j^{-1}\left[\boldsymbol{d}_j - \boldsymbol{\alpha}_j - w_j\boldsymbol{\eta}_j\right] \;\perp\; d_{jks} \geq 0 \quad \text{for all k = 1, …, …,4; s = 1,2 and j = 1, …,5;} \quad (25)$$

$$r_{ijsk} + \delta_{jsk} + g_{isk} \geq b_{jks} \;\perp\; t_{ijsk} \geq 0 \quad \text{for all i = 1, …,8; j = 1, …,5; k = 1, …,4; s = 1,2;} \quad (26)$$

$$h_{isk} + z_{is} \times a_{sk} \geq g_{isk} \;\perp\; p_{isk} \geq 0 \quad \text{for all i = 1, …,8; k = 1, …,4 and s = 1,2; and} \quad (27)$$

$$c_{is} \geq z_{is} \;\perp\; f_{is} \geq 0 \quad \text{for all i = 1, …,8 and s = 1,2.} \quad (28)$$

Some parameters are calculated via summations across input categories. For example, on the supply side, fish farmer costs are defined by $c_{is} = \sum_{n=1}^{10} \lambda_{isn}$ where λ_{isn} is the cost for farm input *n* used to produce a ton of species *s* in region *i*. A parallel calculation of processor cost is given by $h_{isk} = \sum_{m=1}^{7} \mu_{iskm}$, where μ_{iskm} is the cost of processing industry input *m* used to process a ton of species *s* into form *k* in region *i*. Transportation cost is defined by $r_{ijsk} = \gamma_{ij} \times \theta_{sk}$ where γ_{ij} is the distance in kilometers (km) between region *i* and *j* and θ_{sk} is the cost per km of transporting one ton of fish of species *s* in form *k*. Finally, the retailer gross margin, δ_{jsk}, is calibrated as the difference between the total cost (farmers cost, processors cost and transportation cost) and the final price of each product at the retailer level.

Fish farmers and processors are treated in the model as collocated at the same spatial point, so that fish is processed only in the same location where it was farmed. Given the highly perishable nature of fresh fish and observed processing practices, this appears to be a reasonable assumption. Therefore, the cost of transportation between fish farmers and processors is treated as part of the processing cost. This assumption is in accord with observations of the Brazilian fish farming supply chain, where all supply regions *i* in the model represent a group of many farmers that have fish processed in a local facility that can send the processed fish to any demand region *j* in the country.

The model is implemented in the GAMS software as a mixed complementarity problem and solved using the PATH MCP solver. However, the main goal of this model is to estimate the impact of changes in policy and the external economic environment on the locations of demand, supply and quantity flows and regional pricing for each species. These policies and environmental changes are implemented through modification of four parameters: consumers' income (w_j) to reflect income growth over time, retailers' price margin (δ_{jsk}) to assess the importance of retailers behavior in price formation, cost of transportation (θ_{sk}) to reflect international oil price shifts, and fish feed cost (λ_{is1}, where n=1 represents the fish feed input) to reflect governmental intervention through a tax cut for the fish feed industry, which is assumed to be passed on to producers.

4.3 Data

The model is focused on five demand regions (South, Southeast, Midwest, Northeast and North),[5] and eight supply regions (five for tilapia and three for tambaqui – in accord with observed production patterns, no supply region produces both tilapia and tambaqui, and regions do not switch production between species). For purposes of transportation distance estimation, each region is represented by a single large city for demand regions and by a single geographical point where fish production is deemed to be most concentrated for supply regions. Thus, geographical supply points represent the production of tilapia or tambaqui for the whole state, except the states of Bahia (BA) and Pernambuco (PE), which are represented by a single tilapia supply point. Santa Catarina (SC), Parana (PR), Sao Paulo (SP) and Minas Gerais (MG) are the other states that have tilapia supply points in the model. Tocantins (TO), Mato Grosso (MT) and Rondonia (RO) are the states that produce tambaqui in the model. According to the official Brazilian statistics for farmed fish production collected by IBGE in 2018, the states considered in the model represent 78% and 47% of national tilapia and "round" farmed fish production, respectively. The rest of the production of both species are less concentrated, but the data used in this research is nonetheless representative of the total sector.

Figure 4.1 displays the spatial points used in the equilibrium model for demand and supply regions. Tilapia information is divided into two types of production, net cage and pond, because these production systems have different costs. There are four main sources of data used in the

[5] These regions represent the main geopolitical division in Brazil.

model presented: a survey of fish consumers to assess demand as it responds to prices and income, meetings with fish farmers to assess the costs of production, a survey of processing facilities to assess the costs of processing, and Google Maps to assess the costs of transportation. These are discussed in more detail below.

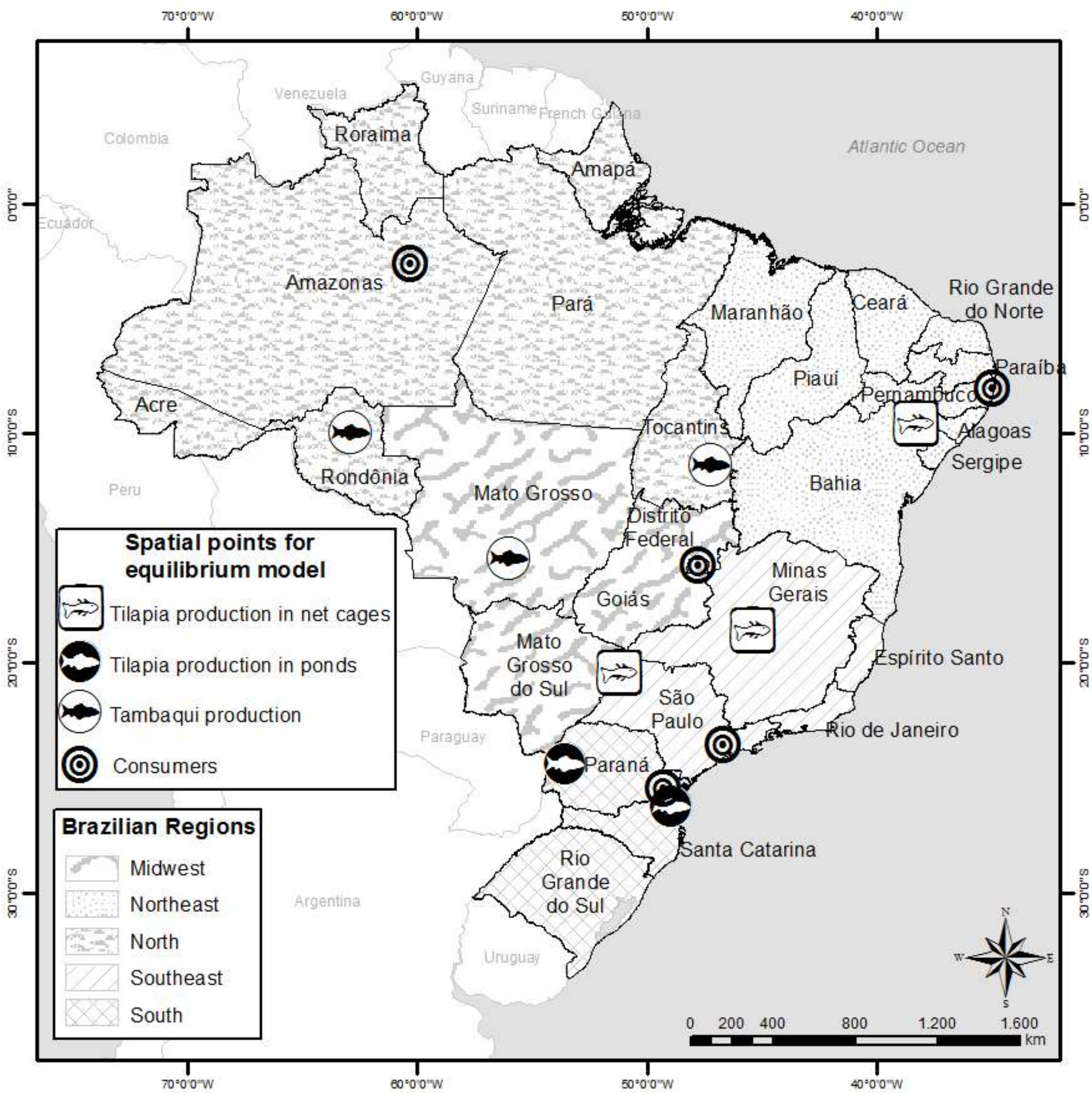

Figure 4.1. Brazilian map with producers and consumers points to be considered in the spatial equilibrium model

4.3.1 Survey of fish consumers

This dataset comes from the fish consumer surveys administered in person in supermarkets of a representative city for each of the five demand regions presented in Chapter 3, with the English translation of the questionnaire presented in Appendix B. The fact that only consumers in front of the fish counter in supermarkets were surveyed is a limitation because information regarding purchasing behavior through other retail establishments (e.g., specialty fish markets, direct purchase from fish farms etc.) is not represented.

Consumers' interviews are used to estimate the responsiveness of annual regional demand by species and form to prices and income. This information on demand response is then used in conjunction with estimated regional demand and price by form and species to calibrate the demand relationships for the equilibrium model. Initial demand values are displayed in Table 4.1, and their estimation is presented in Appendix D. Consumer initial prices are displayed in Table 4.2. Retail prices for all products in the model were collected in July/2019 through calls and online searches focused on at least two supermarkets in the city that is representative of each demand region. The prices are displayed in R$/kg in the table because this is the unit used in the stores, but in the model the values are converted to R$/ton for consistency with demand units.

Table 4.1. Estimated annual demand (tons of processed fish)

	Demand regions				
Products	**South**	**Southeast**	**Midwest**	**Northeast**	**North**
Tilapia					
Fresh whole, cleaned	12891	31439	6173	26893	7285
Fresh fillet	6020	16727	2891	12654	3571
Frozen whole, cleaned	45	223	259	165	18
Frozen fillet	21	119	121	78	9
Total tilapia	18977	48508	9445	39791	10883
Tambaqui					
Fresh whole, cleaned	3957	9651	1895	8256	2236
Fresh fillet	2217	6162	1065	4661	1315
Frozen whole, cleaned	14	68	80	51	6
Frozen fillet	8	44	45	29	3
Total tambaqui	6196	15925	3084	12996	3561

Table 4.2. Retailer final price per product per region

Products	South	Southeast	Midwest	Northeast	North
	Price (R$/kg)				
Tilapia					
Fresh whole, cleaned	8.79	11.25	11.57	11.49	15.90
Fresh fillet	36.60	39.57	40.87	45.49	45.00
Frozen whole, cleaned	11.00	12.00	13.00	13.00	15.90
Frozen fillet	40.12	45.50	45.01	34.87	45.00
Tambaqui					
Fresh whole, cleaned	10.57	12.39	10.90	13.59	9.00
Fresh fillet	24.80	35.00	35.00	35.00	25.00
Frozen whole, cleaned	12.00	12.00	12.00	12.00	10.00
Frozen fillet	24.80	35.00	35.00	35.00	25.00

The matrix of price slopes, $\boldsymbol{\beta}_j$, and the vector of income shifters, $\boldsymbol{\eta}_j$, of the demand function are also estimated using the consumer survey. The detailed estimation procedure and the coefficients obtained and used in the model are described in Appendix E. Average family income (R$/month), w_j, was obtained from the Brazilian National Household Sample Survey (PNAD) administered by IBGE in 2016. Average monthly income values by region are R$ 2249, 2461, 2292, 1352 and 1468 for South, Southeast, Midwest, Northeast and North regions, respectively.

4.3.2 Fish farmers meetings

Production cost information for 5 tilapia and 3 tambaqui supply regions in Brazil was assembled based on meetings with farmers to create a representative farm for each region. Farmer meetings involved at least 20 active farmers from the participating region; they provided current information about input and output prices, production indices and technical requirements for the region. A description of the process of data collection and representative farm formulations can be found in Pedroza Filho et al. (2017). Table 4.3 displays the production cost of fish by input for each region. As in Table 4.2, the prices are displayed in R$/kg because this is the unit that the farmers work with, but in the model the values are converted to R$/ton.

Table 4.3. Fish farming inputs cost (R$/kg)

Inputs	SC	PR	SP	MG	BA/PE	TO	MT	RO
	Supply regions							
Fish Feed	2.96	3.04	3.19	3.42	3.58	3.39	2.50	2.98
Fingerlings	0.20	0.28	0.55	0.17	0.49	0.26	0.22	0.13
Labor	0.53	0.23	0.51	0.41	0.47	0.38	0.51	0.65
Energy	0.22	0.23	0.04	0.09	0.01	0.22	0.25	0.11
Administrative	0.18	0.21	0.07	0.06	0.05	0.16	0.26	0.14
Maintenance	0.10	0.11	0.05	0.06	0.03	0.12	0.17	0.08
Depreciation	0.22	0.24	0.20	0.26	0.18	0.34	0.50	0.21
Land	0.05	0.02	0.00	0.00	0.00	0.04	0.02	0.02
Fertilizer	0.05	0.05	0.00	0.00	0.00	0.01	0.17	0.08
Fish health	0.00	0.02	0.04	0.08	0.03	0.00	0.00	0.02
Total	*4.51*	*4.43*	*4.65*	*4.55*	*4.84*	*4.92*	*4.60*	*4.42*

Note: The numbers presented at this table come from the farmers' meeting and represent the input costs for a constructed representative fish farm of the region, i.e., the most common type of farm (size, input use, location etc.). The zeros in the table show that the input is not used in that region, as land and fertilizer for regions that produce in net cages in dams.

4.3.3 Processing facilities questionnaire

The fish processing facilities questionnaire, which requested data about production costs, input and output prices and processing capacity, is presented in Appendix F. There are about one hundred processing units for tilapia and tambaqui in Brazil and requests to fill out online questionnaires were e-mailed to all of them. Follow up via phone calls and direct contacts was conducted after the initial e-mail. The factories are relatively concentrated near fish farming areas, which serve as the geographical supply locations in the model. In total, 10 questionnaire responses were obtained by August/2019, resulting in a response rate of 10%.

Despite the small number of responses to the survey, processing facilities from different Brazilian Regions provided their processing costs broken down by input per kg of processed fish. Facilities in the South, Southeast and Northeast regions reported the cost to process tilapia fillets. In the North, the cost by input to process whole cleaned tambaqui was provided. In addition, the same facility in the Southeast also provided the cost of processing whole cleaned tilapia. The cost data provided were applied to all supply points in the model present in the same Brazilian region. This is reasonable because there are no significant differences in fish processing technologies (such as mechanization) or final products (other than species) across regions or processing plants. For tambaqui, only one processing facility answered the questionnaire, therefore its cost of processing used is the same for all supply points. The facility that reported the cost of processing for both fillet and whole cleaned tilapia indicated that the processing cost for fillets is three times the cost of processing whole cleaned fish. This ratio is used for every supply point in the country for both tilapia and tambaqui. Fresh and frozen fish present the same processing cost. Table 4.4 presents the processing costs collected. In the table, packaging is the cost related to packaging the final product, as well as some additives to preserve the fish, and maintenance is related to machinery.

Table 4.4. Fish processing inputs cost (R$/kg)

	Region (product)				
Inputs	**South (Tilapia fillet)**	**Southeast (Tilapia fillet)**	**Southeast (Tilapia whole, cleaned)**	**Northeast (Tilapia fillet)**	**North (Tambaqui whole, cleaned)**
Packaging	0.1	0.45	0.15	0.75	0.1
Energy	2.5	0.75	0.25	0.75	0.05
Maintenance	0.1	0.38	0.13	0.25	0.025
Water	0.1	0.38	0.13	0.4	0.025
Labor	1.5	2.55	0.85	2.35	0.025
Administrative	0.2	0.38	0.13	0.25	0.4
Total	*4.50*	*4.89*	*1.64*	*4.75*	*0.63*

Note: The numbers presented at this table come from the processing facilities online survey that had only a small number of respondents. The results here are the average input cost organized by Brazilian region. The results were extrapolated to reach a total processing cost per supply region, species and form.

Two other parameters collected from the processing facilities are the fish yield after processing (a_{sk}) and transportation cost (θ_{sk}). According to information reported by the processing facilities, the yield rate for both tilapia and tambaqui of whole, cleaned fish is 90% of the unprocessed fish weight. For fillets, the tilapia yield is 30% of the whole unprocessed fish by weight, and the tambaqui fillet yield is 40%. The transportation cost does not vary by species, however there is a difference in transport cost depending on whether the fish is fresh or frozen. The average cost reported by the respondents is R$ 0.35 and R$ 0.55 per km to transport one ton of fresh fish and frozen fish, respectively.

4.3.4 Google Maps

The distances between demand and supply regions are obtained from Google Maps and used in conjunction with the per km per ton transport rates to estimate transportation costs from processors to markets. Google Maps bases these distance estimates on the center point of the reference city for each region, and on the shortest road distance. Table 4.5 displays the distances.

Table 4.5. Road distances (km) between supply and demand regions

Supply regions	Demand regions				
	South	**Southeast**	**Midwest**	**Northeast**	**North**
SC	130	531	1505	3172	4176
PR	581	911	1426	3329	3634
SP	817	626	777	2720	3250
MG	1168	758	524	2062	3742
BA/PE	2629	2222	1699	450	4438
TO	2029	1649	683	1842	3699
MT	1694	1528	1086	3190	2346
RO	2969	2791	2347	4451	1090

4.4 Results

To calculate the impacts of changes in the Brazilian fish supply chain, model responses for four scenarios were simulated. A 10% increase in consumers' incomes is analyzed because that was the real per capita income increase in Brazil between 2013 and 2014. That was the most recent year for which data of the Brazilian National Household Sample Survey (PNAD) administered by IBGE was available. This change can be interpreted as a possible scenario for the fish production and demand amounts in the next year if only consumers' incomes increase.

It was observed a large difference between processors' delivered selling prices and the consumer final price – the retailer's gross margin. An increasing in the retailer competition could reduce this margin and a 10% reduction is used to simulate a broadening of competition in the fish retailing sector with larger numbers of markets selling fish within each region. This margin is an indication of the market power of supermarkets in the Brazilian fish chain, since there are only a few chain stores that sell most of the fish.

Variations in the cost of transportation are common due to the dynamics of international oil prices. In Brazil, all fish transport is via roads by trucks using diesel fuel, for which cost is highly correlated with international oil prices. However, the Brazilian government controls the parastatal public corporation that sets the diesel price in gas stations for the whole country. So, changes in national-level transportation costs could also be viewed as a potential policy lever for the government. In the model, it is evaluated the impact of a hypothetical 5% increase in the cost of fish transportation, since it is a typical magnitude for fluctuation in the price of diesel fuel within the country in a year. Fish feed is the highest input cost in fish farming, ranging between 55 and 77% of the total cost of production depending upon the region. The Brazilian government is studying the possibility of a tax cut for factories producing fish feed. Fish farmers associations in Brazil are informally estimating that this tax cut will reduce the fish feed cost for farmers by an average of 8%. Hence, it is assessed the impacts of this cost reduction in the model.

In summary, four scenarios were examined: a 10% consumer income increase, a 10% retailer gross margin reduction, a 5% increase in transportation cost, and an 8% reduction in the cost of fish feed. Table 4.6 displays the impacts of each of these four scenarios on the quantities of national production by species and the regional distribution of production. Because the supply of fish from each region is perfectly elastic, reflecting a lack of binding capacity constraints for either fish farmers or processors, the scenario focused on reduced costs of fish feed is the only scenario that had an impact on prices received by producers; however, the retailer's gross margin reduction and the cost of transportation increase scenarios impact prices further along the supply chain.

Table 4.6. Percentage variation of quantity farmed and fish farming selling price due to parameters change in the spatial equilibrium model

Parameter changed:	**Income (+10%)**	**Retailer gross margin (-10%)**	**Transportation cost (+5%)**	**Fish feed cost (-8%)**	
% variation in:	Farmed quantity	Farmed quantity	Farmed quantity	Farmed quantity	Selling price
National	2.3	6.7	-0.15	2.4	-5.4
By species					
Tilapia	2.5	6.5	-0.04	2.6	-5.5
Tambaqui	1.7	7.2	-0.48	1.5	-5.2
By state					
Santa Catarina	3.3	5.3	0.11	2.9	-5.3
Parana	3.1	9.5	-0.10	2.9	-5.5
Sao Paulo	1.6	3.0	-0.07	1.8	-5.5
Minas Gerais	-0.2	10.3	-0.11	4.6	-6.0
Bahia/Pernambuco	1.2	2.7	0.04	2.7	-5.9
Tocantins	0.3	7.1	-0.66	1.4	-5.5
Mato Grosso	1.2	7.4	-0.53	-0.1	-4.3
Rondonia	2.2	7.1	-0.42	2.3	-5.4

An increase of consumers' income by 10% increased the total tilapia and tambaqui farmed in Brazil by 2.3% in the model. The impact of income is higher for tilapia than tambaqui and the differences among supply regions are due to which product they produce and its destination. Minas Gerais, for example, different from the other regions, produce less tilapia with an income increase because it sells most of its production to the Midwest region, where frozen fish products are inferior goods.

The change in retailers' gross margin has a higher impact on national and regional production because it represents, on average, 48.3% of the final fish price in Brazil. Thus a 10% decrease of the gross retail margin results in an increase in the total tilapia and tambaqui farmed by 6.7%. Unlike the income change scenario, the reduction in retailers' gross margins has the highest impact in Minas Gerais for total farmed fish. This is because the Midwest is the region with the highest margins for tilapia. On the other hand, Bahia and Pernambuco sell their production in the Northeast, which has lower margins, and so the 2.7% increase of total farmed fish in that producing region is also lower. At the national level, tambaqui shows a larger impact from a reduction in retailers' gross margin than tilapia, and in the tambaqui production regions (Tocantins, Mato Grosso and Rondonia), there is little difference in the observed changes in regional production.

The transportation cost reduction scenario has the least impact on production in the supply chain, because transportation cost accounts for only 3.5% of the retail fish price. The importance of this parameter for tambaqui is much higher than for tilapia because, in general, tambaqui is produced further from demand regions. For tilapia, the impact of a 5% increase in transportation costs causes small changes in the farmed quantity. Regions like Santa Catarina and Bahia and Pernambuco that have shorter distances between supply and demand points, start supplying to regions they were not supplying before, and therefore experience an increase in production quantity even with more expensive transportation compared to the other supply regions that sell to far away demand centers.

The results of the scenario with an 8% reduction in fish feed costs indicate lower selling prices for farmers – on average 5.4% lower. Feed constitutes more than half of total costs of fish production and the impact on production reflects the importance of this input. For this scenario, the supply regions that produce tilapia in net cages (Sao Paulo, Minas Gerais and Bahia and Pernambuco) have higher impacts on selling prices because the net cage production system uses fish feed more intensively than earthen ponds. This is because in earthen pond fish farming, fish have other sources of feed like phytoplankton, and hence, the feed conversion ratio (FCR) is lower, resulting in less commercial fish feed usage. The difference between both species is large, with tilapia showing a production increase of almost 2.6%. In Parana, the supply region with the largest production in Brazil, a slightly higher increase of 2.9% is observed.

The impacts of the same scenarios are displayed at the consumers' end of the supply chain in Table 4.7, including consumer demand and final product prices. The impact on the national average price was calculated by weighting regional prices by regional demand quantities. The scenario with higher consumer incomes does not affect the final price because the supply curve in the model is horizontal at the total cost of production, processing, transport and retailing. A 10% increase in consumers' income increases the total tilapia and tambaqui demanded in Brazil by 2%. This result is different from what was found by Flores and Pedroza Filho (2014) where a percentage point change in income in Brazil corresponds to a change of 0.97% in fish consumption. Most of the demand impact of the income scenario comes from the Southeast and South, regions with larger population and income, with a 2.5% and 2.4% change in demand, respectively. The percentage impact for frozen products is much larger, but the demand for frozen fish was a quite small fraction in the initial total demand.

Table 4.7. Percentage variation of demand and final price due to parameters change in the spatial equilibrium model

Parameter changed:	**Income (+10%)**	**Retailer gross margin (-10%)**		**Transportation cost (+5%)**		**Fish feed cost (-8%)**	
% variation in:	Demand	Demand	Final price	Demand	Final price	Demand	Final price
National	2.0	5.4	-5.2	-0.15	0.1	2.2	-1.9
By species							
Tilapia	2.2	5.0	-5.1	-0.04	0.1	2.5	-2.0
Tambaqui	1.5	6.6	-5.5	-0.47	0.2	1.2	-1.7
By region							
South	2.4	3.8	-4.4	-0.08	0.1	2.2	-2.2
Southeast	2.5	5.6	-5.2	-0.13	0.1	2.1	-1.9
Midwest	1.3	5.5	-5.2	-0.12	0.1	2.1	-1.9
Northeast	1.4	5.9	-5.3	-0.18	0.1	2.3	-1.9
North	1.7	5.2	-5.4	-0.23	0.2	1.9	-1.6
By form							
Fresh whole, cleaned	1.5	3.2	-4.2	-0.08	0.1	1.8	-2.3
Fresh fillet	2.9	8.4	-5.6	-0.15	0.1	2.5	-1.7
Frozen whole, cleaned	5.1	42.3	-4.4	-5.90	0.1	10.3	-2.0
Frozen fillet	10.0	78.4	-5.9	-3.31	0.1	20.0	-1.6

Table 4.7 also shows that retailers' gross margin is an important factor in the chain. A 10% reduction will decrease prices by 5.2% and increase the demand quantity by 5.4% at the national level. This impact is lower for tilapia than for tambaqui and lower for the South region. Again, the results for frozen products are very high in percentage terms, but their initial demand is still small relative to the demand for fresh products. On the other hand, the impacts for transportation cost changes are much lower. A 5% change has an impact of only 0.1% on the final price and 0.15% on the demand quantity. This result is even lower for tilapia, where the reduction in demand is only 0.04%.

The impact for a fish feed cost reduction on demand is also important, but the decrease in final price is lower than the decrease in farmers' costs and hence selling price. This shows that a reduction in an input cost has a higher impact for the farmers' selling prices, but the impact will decrease in percentage terms as the fish move through the supply chain due to other costs. The impact is larger for tilapia than for tambaqui, since there is no net cage production of tambaqui in the model, which needs more fish feed per unit of fish produced.

4.5 Conclusions

This essay develops an empirical spatial equilibrium model for the Brazilian supply chain for the two major farmed-fish species, tilapia and tambaqui. The impact of the alternative scenarios on model results should be of interest for farmers, processors, retailers, consumers and policy makers. The possibility of changing transportation cost through oil prices or road improvements is a relatively ineffective means addressing prices along the chain because transportation cost does not have a large share in the final retail price. However, this factor would be relatively more important for tambaqui production and demand due to the fact that that species is generally produced further from markets. Hence, while the production of tambaqui is lower than tilapia at present, a transportation cost reduction will make the quantity produced of both species more similar. The other three parameter changes studied presented higher impacts in the supply chain, especially retailers' gross margin. A change in retailers' gross margin would result in important changes along the chain, but it is a factor that does not depend directly on government decisions and actions.

The relationship between income and demand is also shown in this essay. In the past ten years, per capita incomes did not increase, but there was significant growth in fish production. An income increase would further increase fillet consumption because it is a more expensive product, more desired by high income consumers.

Finally, a tax reduction on fish feed production studied by the government, resulting in an 8% reduction in the input cost for fish farmers, would have a significant impact across whole supply chain, especially for tilapia, which has a significant share of production in net cages and hence uses feed more intensively. This tax cut would increase the total Brazilian demand by 2.2%, suggesting that this might be an effective government policy for stimulating expansion of the aquaculture industry in Brazil.

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CHAPTER 5. CONCLUSIONS

The Brazilian government recognized the growth of the aquaculture sector and the demand for protein in recent decades, and implemented important actions to support this area in the beginning of the current century. Examples of actions taken by the government included the creation of the Special Secretariat of Aquaculture and Fisheries in 2003, the opening of an aquaculture unit of research at the Brazilian Agricultural Research Corporation (Embrapa) in Palmas, state of Tocantins, in 2009, and the development of the Fisheries and Aquaculture Production Plan in 2012.

In spite of the government efforts, the aquaculture sector in Brazil has several structural problems and challenges. More studies are required to identify the needs of the production sector, such as extension, feeds, environmental license and access to credit. Reliable statistical data on the Brazilian aquaculture sector is also lacking. The demand for economic data includes aspects such as the characterization of the supply chain, the markets and financial indicators of producing units. This dissertation is organized in three essays and fills some of the economic data gaps. Information is collected from suppliers and consumers of tilapia and tambaqui, the two most important fish farming species in Brazil.

The first essay utilizes data from an experimental study of the productivity of an aquaponics system conducted at UNESP's (Sao Paulo State University) experimental aquaponics facility. Four different initial fingerling stocking densities and four feeding rates relative to the manufacturer's recommendations were measured in a 30-day experiment producing lettuce and juvenile tilapia. Efficiency analysis of this data showed that the best system is fairly robust but is somewhat sensitive to the prices of juvenile fish and lettuce output. A complete financial analysis was done with this system and the results suggest that aquaponic production of tilapia in tandem with lettuce is economically viable in a 10-year project period. The model results provide important information for current and potential farmers that is useful in assisting them to better assess options for investment in aquaponics relating to input use, cost and profits, and producing fish and vegetables in a more sustainable way. Although the experiment was conducted in Brazil, the results can be easily applied in other production environments.

The second essay estimates the WTP for fillets of tilapia and tambaqui. On average, Brazilian fish consumers prefer tilapia to tambaqui and fresh to frozen fillets. Results suggest strong relationships between fish knowledge and species selection preferences, indicating potential room for communication and/or marketing to improve shopper awareness of fish availability. The results of this research improve the understanding of the preferences of Brazilian consumers in different regions for different fish species and product forms, and helps to inform decisions relating to fish production, product forms and product availability. This work is novel because there has not been a national study of seafood preferences considering factors such as product form, species, and fish knowledge. Seafood supply chains, from fish farmers to supermarkets selling direct to consumers, must understand consumer demand for product attributes to ensure production and availability of desired products. The improved knowledge regarding consumer preference for tilapia and tambaqui can be used by farmers and the processing industry for production planning, as well as by wholesale and retail sellers for supply chain planning.

The third essay develops an empirical spatial equilibrium model for the Brazilian supply chain for tilapia and tambaqui. The results show that changes in transportation costs, impacted by oil prices or road improvements had little impact on market outcomes. A 10% reduction of retailers' gross margins decreased prices by 5.2% and increased quantity demanded by 5.4%, while an 8% reduction in fish feed costs due to tax cuts indicated, on average, 5.4% lower selling prices for farmers. The work is novel for several reasons. First, this is an empirical analysis of a supply chain that has received little attention. Second, the approach to constructing the demand relationships is novel. In addition, substantial empirical data was developed in the process of model building, which has value in its own right. Finally, the resulting asymmetric demand system is incorporated in the model by employing the mixed complementarity problem framework for the formulation.

Besides the novelty of the research, this dissertation has limitations. In the first essay, the experiment was conducted in very specific conditions like climate, selected plants and starting size of fingerlings, for example. The economic viability was tight which shows that this activity needs more research to identify best practices and encourage farmers to invest in it. In the second essay, a survey was conducted in supermarkets of only one city in each region and the choice experiment considered only the fillet form of each species. Those facts indicate that there is space for new approaches in future research aiming to understand the fish consumption habits of other parts of the Brazilian population. The third essay uses a complex model that requires a large amount of data to be specified. Some simplifying assumptions were made either due to a lack of available information or to make the model computationally tractable. For example, regional consumers and producers were assumed to be concentrated at one spatial point per region; price and income elasticities for fillet and whole cleaned fish were assumed to be equal; and processing facilities were assumed to only buy fish from the farms in the same spatial point.

Despite the limitations, this dissertation provides information for the government and private institutions working on aquaculture in Brazil. First, aquaponics is a risky activity in terms of economic returns and finding the best use of inputs is essential to have success. The fact that aquaponics has environmental benefits, especially for dry regions, is an additional benefit that was not explicitly valued in the analysis. To exploit this benefit, the government may wish to support aquaponic production activities through facilitating new investments and offering rural extension and applied production research. Second, the results suggest strong relationships between fish knowledge and species selection preferences, and since Brazil has many native fish species that could be farmed but some of these are unfamiliar to much of the population, the government and entrepreneurs may wish to invest in education and advertisement to enlighten consumers regarding alternative fish species. Third and finally, special attention should be given to supermarket retailers gross margins because even small changes in this value have a significant impact in the final prices and quantities demanded of fish in the country. The difference between the fish price sold by processors and the fish price for consumers in the supermarket is very large and the market concentrations of those retailers may be one of the explanations. Although cutting taxes for fish feed production could increase the farmed fish production, a policy focused on retailers pricing could bring larger changes in the final demand.

APPENDIX A. AQUAPONICS EXPERIMENT PICTURES

Photo credit: Laura Patricia Silva Ledezma

Photo credit: Laura Patricia Silva Ledezma

Photo credit: Laura Patricia Silva Ledezma

APPENDIX B. QUESTIONNAIRE APPLIED WITH CONSUMERS IN BRAZILIAN SUPERMARKETS

Enumerator______ Date/Time_______ City ________ Supermarket________ Fish day: □ Yes

This survey should take no more than 7 minutes to complete. You must be at least 18 years of age and be a resident of this city to participate. Your participation in this study is voluntary and your responses to the questionnaire will be treated as confidential. Your name is not required anywhere and all survey data will be combined to ensure the anonymity of your individual responses.

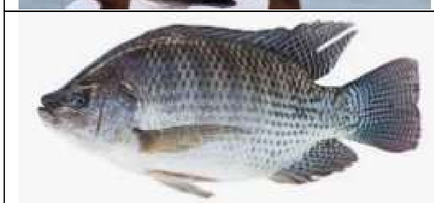
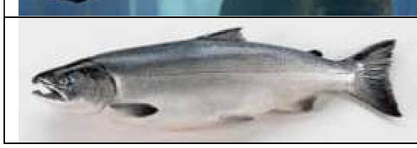
1) **What is your gender?** **□ a) M** **□ b) F**

2) **How old are you? _______________**

3) **Does your family eat fish?**

□ a) YES
□ b) NO (Give reason __________________________________) Terminate interview

4) **Can you identify each species in the pics?**

	tilapia	tambaqui	pirarucu	salmon	Pintado (catfish)	Don't know
						
						
						
						
						

Did the consumer change any answer in this question? □ yes □ no

5) Could you identify the fillet of each species in the pics?

	tilapia	tambaqui	pirarucu	salmon
				
				
				
				

Did the consumer change any answer in this question? □ yes □ no

Which option of fish would you buy? (Use a picture of each to show the interviewed)

Question	Option A	Option B	Option C
6)	Tilapia Frozen R$ 32.00	Tilapia Fresh R$ 35.00	If these were the only fish options available, I would not buy fish at this time.
7)	Tilapia Frozen R$ 35.00	Tambaqui Frozen R$ 28.00	If these were the only fish options available, I would not buy fish at this time.
8)	Tilapia Frozen R$ 25.00	Tambaqui Fresh R$ 25.00	If these were the only fish options available, I would not buy fish at this time.
9)	Tilapia Fresh R$ 32.00	Tambaqui Frozen R$ 32.00	If these were the only fish options available, I would not buy fish at this time.
10)	Tilapia Fresh R$ 35.00	Tambaqui Fresh R$ 35.00	If these were the only fish options available, I would not buy fish at this time.
11)	Tambaqui Frozen R$ 32.00	Tilapia Frozen R$ 25.00	If these were the only fish options available, I would not buy fish at this time.
12)	Tambaqui Frozen R$ 28.00	Tilapia Fresh R$ 32.00	If these were the only fish options available, I would not buy fish at this time.

13)	Tambaqui Fresh R$ 35.00	Tilapia Frozen R$ 32.00	If these were the only fish options available, I would not buy fish at this time.
14)	Tambaqui Fresh R$ 28.00	Tilapia Fresh R$ 25.00	If these were the only fish options available, I would not buy fish at this time.

15) How many people live in your home? _______________

16) How many people under 12 years old live in your home? _______________

17) On average, how much is spent on food in a month for the whole family? _________

18) On average, how much is spent on fish in a month for the whole family? __________

19) Where do you usually buy fish? (please check all that apply)

□ a) Supermarket
□ b) Fish store
□ c) Butcher shop
□ d) Farmers market
□ e) City market
□ f) Direct from fishers / fish farmers
□ g) Other (please specify) _______________

20) Which of these forms of fish do you usually buy?

	Never	**Occasionally**	**At least once a month**	**Every 15 days**	**At least once a week**	**At least twice a week**	**Daily**
	Processing						
Fillet							
Strips							
Chunk							
Whole fish							
Canned							
	Conservation						
Fresh							
Frozen							
Salted							
Cooked							

21) Which of these types of fish do you prefer the most?

□ a) Fresh water
□ b) Sea / Salt water
□ c) Indifferent

22) If you can choose between two fish from the same species, do you prefer?

□ a) Farmed. Why? _______________
□ b) Wild-caught. Why? _______________
□ c) Indifferent

23) Do you know how these fish are produced?

	Wild-caught	Farmed	Both	Do not know
□ a) Tilapia				
□ b) Tambaqui				
□ c) Salmon				
□ d) Sardine				
□ e) Pintado (catfish)				

24) Which one of the following do you prefer?

□ a) Saint Peter fillet
□ b) Tilapia fillet
□ c) Indifferent
□ d) They are the same
□ e) Do not like either/Did not eat both
□ f) I do not know one or both of these fillets

25) Which of these represents the total monthly family income?

□ a) Less than R$ 1.254
□ b) Between R$ 1.255 and R$ 2.004
□ c) Between R$ 2.005 and R$ 8.640
□ d) Between R$ 8.641 and R$ 11.261
□ e) More than R$ 11.262

26) What is your highest level of education?

□ a) No formal school
□ b) Primary school - incomplete
□ c) Primary school - complete
□ d) High school – incomplete
□ e) High school - complete
□ f) Bachelor - incomplete
□ g) Bachelor – complete
□ h) Graduate

APPENDIX C. SOCIODEMOGRAPHIC, FISH CONSUMPTION AND FISH KNOWLEGDE VARIABLES FOR CONSUMERS WITH HIGHER AND LOWER PREFERENCES ON FISH ATTRIBUTES

Tilapia - lower than p10	Tilapia - higher than p90
South	
More able to identify the whole tambaqui picture (93%)	More able to identify the whole tilapia picture (75%)
Less able to identify the tilapia fillet picture (39%)	More able to identify the tilapia fillet picture (93%)
Higher average monthly consumption on fish (R$ 251)	Know more St Peter and tilapia fillet are the same (29%)
Buy more in farmers markets (40%)	Purchase more fish fillet at least occasionally (93%)
Prefer more fresh water fish (73%)	
Know less that Saint Peter and tilapia fillet are the same (0%)	
Purchase less fish fillet at least occasionally (38%)	
Southeast	
Lower woman percentage (33%)	More consumers are younger than 40 years old (47%)
More able to identify the whole tambaqui picture (89%)	More able to identify the tilapia fillet picture (83%)
More able to identify the whole pirarucu picture (81%)	Lower average monthly consumption on fish (R$ 114)
Higher average monthly consumption on fish (R$ 210)	Buy less in farmers markets (3%)
Buy less in fish stores (7%)	Prefer more sea/salt water fish (47%)
Buy more in farmers markets (37%)	Know more St Peter and tilapia fillet are the same (17%)
Prefer more fresh water fish (73%)	Purchase more fish fillet at least occasionally (93%)
Prefer more wild-caught fish (73%)	
Higher knowledge about how tambaqui is produced (50%)	
Midwest	
Higher woman percentage (72%)	Lower woman percentage (28%)
More able to identify the whole tambaqui picture (86%)	More consumers are younger than 40 years old (43%)
Less able to identify the tilapia fillet picture (14%)	Less able to identify the whole tambaqui picture (29%)
More kids at home on average (1.0)	Prefer less sea/salt water fish (10%)
Higher average monthly consumption on fish (R$ 289)	Prefer less wild-caught fish (48%)
Buy less in fish stores (0%)	Higher presence in income classes D and E (45%)
Buy more in farmers markets (32%)	Purchase more fish fillet at least occasionally (95%)
Know less that Saint Peter and tilapia fillet are the same (0%)	Purchase less whole fish at least occasionally (43%)
Purchase less fish fillet at least occasionally (41%)	
Purchase less frozen fish at least occasionally (31%)	
Higher knowledge about how tambaqui is produced (54%)	
Northeast	
More able to identify the whole tambaqui picture (93%)	Lower average monthly consumption on fish (R$ 111)
Lower average monthly consumption on food (R$ 972)	Buy less in farmers markets (0%)
Higher average monthly consumption on fish (R$ 258)	Purchase more fish fillet at least occasionally (96%)
Buy more in farmers markets (40%)	Purchase less whole fish at least occasionally (54%)
Prefer more fresh water fish (73%)	Purchase more frozen fish at least occasionally (90%)

Prefer more wild-caught fish (80%)	
Know less that Saint Peter and tilapia fillet are the same (0%)	
Higher presence in income classes A and B (31%)	
Purchase less fish fillet at least occasionally (57%)	
Purchase more whole fish at least occasionally (97%)	
Purchase less frozen fish at least occasionally (30%)	
Higher knowledge about how tambaqui is produced (53%)	
North	
More consumers are older than 50 years old (58%)	More able to identify the whole tilapia picture (78%)
More able to identify the whole tambaqui picture (96%)	Less kids at home on average (0.25)
Less able to identify the tilapia fillet picture (29%)	Prefer more farmed fish (13%)
More kids at home on average (0.52)	Purchase less whole fish at least occasionally (42%)
Buy more in farmers markets (37%)	Lower knowledge about how tambaqui is produced (23%)
Prefer more fresh water fish (65%)	
Prefer more wild-caught fish (74%)	
Know less that Saint Peter and tilapia fillet are the same (0%)	
Purchase less fish fillet at least occasionally (52%)	
Purchase more whole fish at least occasionally (91%)	
Higher knowledge about how tambaqui is produced (65%)	

Fresh - lower than p10	Fresh - higher than p90
South	
Less kids at home on average (0.25)	More able to identify the tambaqui fillet picture (62%)
Buy more in supermarkets (90%)	More able to identify the tilapia fillet picture (80%)
Purchase less fresh fish at least occasionally (79%)	Prefer less sea/salt water fish (13%)
Purchase more frozen fish at least occasionally (71%)	Purchase less frozen fish at least occasionally (34%)
	Higher presence in income classes D and E (41%)
Southeast	
Higher woman percentage (70%)	Higher woman percentage (75%)
Less able to identify the whole tambaqui picture (20%)	Higher average monthly consumption on food (R$ 1590)
Less kids at home on average (0.29)	Higher average monthly consumption on fish (R$ 199)
Buy less in farmers markets (0%)	Lower presence in income classes A and B (11%)
Prefer less wild-caught fish (29%)	Lower presence in educational level at most primary (4%)
Lower presence in income classes A and B (14%)	Purchase less frozen fish at least occasionally (36%)
Higher presence in educational level at most primary (21%)	
Purchase less fresh fish at least occasionally (75%)	
Purchase more frozen fish at least occasionally (89%)	
Midwest	
Lower man percentage (41%)	More consumers are older than 50 years old (57%)
Less able to identify the tambaqui fillet picture (10%)	Buy less in supermarkets (62%)
Prefer more farmed fish (18%)	Prefer more wild-caught fish (58%)
Higher presence in income classes A and B (48%)	Lower presence in income classes A and B (6%)
Purchase more frozen fish at least occasionally (82%)	Purchase more fresh fish at least occasionally (100%)

	Purchase less frozen fish at least occasionally (47%)
Northeast	
Higher woman percentage (73%)	Higher woman percentage (83%)
Prefer less fresh water fish (13%)	More consumers are older than 60 years old (23%)
Higher presence in graduate educational level (40%)	More able to identify the tambaqui fillet picture (67%)
	More able to identify the tilapia fillet picture (83%)
	Higher average monthly consumption on fish (R$ 215)
	Buy more in supermarkets (93%)
	Buy more in fish stores (30%)
	Higher presence in income classes D and E (45%)
	Purchase more fish fillet at least occasionally (93%)
North	
More consumers are older than 40 years old (54%)	More able to identify the whole tilapia picture (72%)
Less able to identify the tilapia fillet picture (36%)	More able to identify the tilapia fillet picture (92%)
More kids at home on average (0.6)	Purchase more fish fillet at least occasionally (96%)
Lower average monthly consumption on fish (R$ 107)	Purchase less frozen fish at least occasionally (29%)
Prefer more sea/salt water fish (50%)	
Prefer less wild-caught fish (18%)	
Purchase more frozen fish at least occasionally (96%)	
Lower knowledge about how tambaqui is produced (5%)	

APPENDIX D. DEMAND INITIAL VALUES ESTIMATION

Demand initial values are estimated considering the total quantity of tilapia and “round” fish species produced in the supply regions (states) and the population, the average fish consumption and the market share per fish product in the demand regions of the equilibrium model.

Market share is calculated from the choice experiment presented in Chapter 3 and the survey question about which forms of fish the consumer usually buys (question 20 in Appendix B). Market shares are estimated using the average price per kg in the choice experiment (R$ 30) to predict v from Equation (18) and use it in Equation (15) (both equations present in Chapter 3) for all combinations of species and forms. Table D.1 presents the estimates for market shares of fish fillets according to the choice experiment. Because the choice experiment was done only considering fillet and in the equilibrium model there is also whole, cleaned fish, to estimate the total market share, the answers to question 20 in Appendix B “Which of these forms of fish do you usually buy?” is used to calculate the percentage of consumers that never buy fillet or whole, cleaned fish. Table D.1 also presents the results for this question by region.

Table D.1. Market shares for fish fillet and percentage of consumers that never buy whole, cleaned fish or fillet

	Demand regions				
	South	**Southeast**	**Midwest**	**Northeast**	**North**
Fillet market share (%)					
Fresh tilapia	91.0	90.9	82.3	81.5	88.7
Frozen tilapia	0.3	0.6	3.5	0.5	0.2
Fresh tambaqui	8.6	8.4	13.7	17.9	11.0
Frozen tambaqui	0.03	0.06	0.58	0.11	0.03
Never buy (%)					
Whole, cleaned	33.7	38.9	33.7	32.9	36.6
Fillet	16.4	12.2	16.1	14.7	16.1

The total market shares for all forms are calculated according to the following formula:

$$MS_{jsk} = FMS_{jsk} \times \frac{BF_{jk}}{\sum_{k'} BF_{jk'}} \quad , \tag{D1}$$

where MS_{jsk} is the total market share for region j, species s and form k; FMS_{jsk} is the market share for fillet in way of preservation k (fresh or frozen) of species s in region j, presented in the first part of Table D.1; and BF_{jk} is the proportion of consumers in region j that buy fish in the form k (whole, cleaned or fillet form), according to the second part of Table D.1. Table D.2 presents the total market shares (MS_{jsk}).

Table D.2. Total market share estimation for Brazilian consumers

	Demand regions				
Products	**South**	**Southeast**	**Midwest**	**Northeast**	**North**
Tilapia					
Fresh whole, cleaned	40.3%	37.3%	36.3%	35.9%	38.2%
Fresh fillet	50.8%	53.6%	45.9%	45.6%	50.6%
Frozen whole, cleaned	0.1%	0.3%	1.5%	0.2%	0.1%
Frozen fillet	0.2%	0.4%	1.9%	0.3%	0.1%
Total tilapia	**91.4%**	**91.5%**	**85.7%**	**82.0%**	**89.0%**
Tambaqui					
Fresh whole, cleaned	3.8%	3.5%	6.1%	7.9%	4.7%
Fresh fillet	4.8%	5.0%	7.7%	10.0%	6.3%
Frozen whole, cleaned	0.0%	0.0%	0.3%	0.1%	0.0%
Frozen fillet	0.0%	0.0%	0.3%	0.1%	0.0%
Total tambaqui	**8.7%**	**8.5%**	**14.3%**	**18.0%**	**11.0%**

In Brazil, there is not official data for demand of fish. Therefore, it is necessary to find a way to estimate numbers per specie, form and region that allow the equilibrium model to calculate reasonable optimized quantities. To calculate the demand for whole (before processing) tilapia and tambaqui, total production for both species in the states that are suppliers in the equilibrium model is used, i.e., it is driven regional demand off regional supply. According to IBGE, the total fish farmed in these states in 2017 was 221,514 tons of tilapia and 67,999 tons of tambaqui. These production numbers are multiplied by the market share for the respective species consumption, according to Table D.2, and by a regional weight. The regional weight is calculated from the multiplication of the total population in each region in 2017, according to IBGE, and the average monthly consumption of fish according to the question 18 in Appendix B. The final weight by region is displayed in Table D.3. Finally, to estimate the final demand showed in the Table 4.1

used in the equilibrium model, the results for tilapia and tambaqui are multiplied by the processing yield, 90% for whole, cleaned fish, 33% for tilapia fillet and 40% for tambaqui fillet.

Table D.3. Fish consumption weights by region

Region	Population	Average monthly fish consumption (R$)	Weight
South	27,731,644	161.66	14.7%
Southeast	81,565,983	144.98	38.7%
Midwest	14,423,952	154.80	7.3%
Northeast	53,907,144	174.69	30.8%
North	16,318,163	159.39	8.5%

APPENDIX E. ESTIMATION OF THE MATRIX OF PRICE SLOPES AND THE VECTOR OF INCOME SHIFTERS OF THE DEMAND FUNCTION

To model the effects of price and income changes on the demand for fish, a linear demand system was developed. The system expresses the vector of fish quantities by species and form as a function of prices for the different species and forms, as well as income. This demand system is estimated from a simulated data set that reflects the estimated market share responses to fillet prices calculated in Appendix D from the choice experiment presented in Chapter 3 and Appendix B as well as some secondary information regarding the own price elasticity of demand for aggregate fish. Preferences for the products in the model (combinations of form and species) are used to calculate the individual market shares with all combinations of each component of the fillet price vector set to either the average level, R$ 30 or with a 10% increase, R$ 33. This estimation starts with a regional fillet demand system and uses it to generate demands for whole, cleaned fish too. To calculate the individual market shares for fillets, the β_{mn} parameters associated with the attributes in Equation (16) of Chapter 3 for the attribute m and the consumer n are used. Those parameters are used to predict the individual deterministic part of the utility, v_n, from Equation (18), which is used in Equation (15) for each combination of species and forms. This calculation is a process similar to the fillet market shares calculation in Appendix D, but here it is done for each participant of the consumer survey and for all combination of prices at R$ 30 and R$ 33.

For each price vector, the prices and corresponding market shares are used to calculate a weighted price for aggregate fish. In the questionnaire administered in the supermarkets, the consumers indicated their family average expenditures on fish per month (question 18 in Appendix B). Dividing this expenditure by the R$ 30 average price and multiplying by 12 from the survey yields a base quantity of fish in kg per year for each family. The change in the aggregate fish price is combined with the base quantity of fish and the own price elasticity of fish demand in the country of -0.7 (Sonoda et al., 2012) to calculate a new level of yearly aggregate fish demand. The new aggregate fish demand is then distributed per consumer according to the individual market shares to obtain the quantity consumed per product.

To capture income variation, it is considered the survey question that asked the consumer to classify his family income in one of five income ranges (question 25 in Appendix B). Therefore, for the linear demand system regression, the midpoint value for each income range option is used. For the highest income range, because there is no maximum value, the representative value for the range was estimated using a linear regression with the other four midpoints for each range.

Having the individual quantity consumed per product according to all combinations of each component of the price vector set to either R$ 30 or R$ 33 and the income level, the coefficients are estimated using a seemingly unrelated regression (SUR) with observed exogenous variables and uncorrelated errors:

$$\ddot{\boldsymbol{d}}_{jn} = \ddot{\boldsymbol{\alpha}}_{jn} + \ddot{\boldsymbol{\beta}}_j \ddot{\boldsymbol{b}} + \ddot{\boldsymbol{\eta}}_j \ddot{w}_{jn} + \ddot{\boldsymbol{\xi}}_{jn}, \tag{E.1}$$

where $\ddot{\boldsymbol{d}}_{jn}$ is a vector with the quantity consumed per product per year by the family of consumer n in region j according to the market shares estimation, $\ddot{\boldsymbol{\alpha}}_{jn}$ is a vector of intercepts, $\ddot{\boldsymbol{b}}$ is a vector of prices with elements being 30 or 33, $\ddot{\boldsymbol{\beta}}_j$ is the matrix of prices coefficients, $\ddot{w}_{jn}$ is the range midpoint of the family income of consumer n in region j, $\ddot{\boldsymbol{\eta}}_j$ is the vector of income coefficients, and $\ddot{\boldsymbol{\xi}}_{jn}$ is the error term of the regression.

Having $\ddot{\boldsymbol{\beta}}_j$ and $\ddot{\boldsymbol{\eta}}_j$ estimated, it is necessary to convert the units of their elements to reach the slopes of regional demand by species and form with respect to prices, $\boldsymbol{\beta}_j$, and income, $\boldsymbol{\eta}_j$. These parameters are used in the equilibrium model to construct the social welfare objective. The elements in the matrix $\ddot{\boldsymbol{\beta}}_j$ represent the effect of a change in the price in R$/kg on the demand of the product in kg of fish per family surveyed. However, the elements in the matrix $\boldsymbol{\beta}_j$ to be used in the equilibrium model need to reflect the impact of a change in the price in R$/ton on the demand of the product in tons of just tilapia and tambaqui per region. The first step is to convert kg to tons, both in price and in quantity demanded. Therefore, $\ddot{\boldsymbol{\beta}}_j$ is divided by one thousand twice, i.e., by one million. The second step is to divide $\ddot{\boldsymbol{\beta}}_j$ by 19.12 to convert the results for a family that participated in the survey to a per capita basis. The value 19.12 is calculated dividing the annual family average fish consumption observed in the survey (190.12 kg/family) by the annual Brazilian per capita fish consumption (10 kg/person) (PEIXEBR, 2019). The third step is to multiply $\ddot{\boldsymbol{\beta}}_j$ by 16.45%, the estimated share of tilapia and tambaqui produced by the supply regions in the model in the Brazilian market, to convert the results in fish (all species) to tilapia and tambaqui. This share was estimated using data of the Brazilian Institute of Geography and Statistics (IBGE) for fish production, exports and imports in 2018, dividing the tilapia and tambaqui consumption (total farmed tilapia and tambaqui in the supply regions minus total exported tilapia and tambaqui)[6] by total fish consumption in Brazil (total farmed fish plus total wild-caught fish[7] plus total imported fish minus total exported fish). Finally, $\ddot{\boldsymbol{\beta}}_j$ is multiplied by the region population in 2017 according to IBGE (Table D.3) to end up with the results in tons of tilapia and tambaqui by region.

Another point is that the choice experiment was done only with fish fillet products and the regression above is estimated for those products. However, the equilibrium model will also include whole, cleaned fish products for which there is no available data to estimate the similar coefficients. It will be assumed that the ratio of fillet price of fish products (by species, form and region) presented in Table 4.2 divided by price of whole, cleaned fish products will be a constant. Therefore, to calculate the coefficients for whole, cleaned fish, the elements of $\boldsymbol{\beta}_j$ for fillet prices are multiplied by this ratio for every region, species and form (fresh or frozen). In addition, no substitution between fillet and whole, cleaned products is assumed. Table E.1 and E.2 presents the price slopes for fillet and for whole, cleaned fish, respectively, to be used in the model.

[6] Both species are only farmed and not imported in Brazil.

[7] The total wild-caught fish considered comes from the Ministry of Fisheries and Aquaculture report in 2013, since IBGE does not have statistics for wild-caught fish in Brazil. This is the most recent data about this sector, but, since it is a natural resource, the total wild-caught production is steady in the past years.

Table E.1. Price slopes of the demand function for fillet

Quantity consumed (tons/region)	Fresh tilapia price (R$/ton)	Frozen tilapia price (R$/ton)	Fresh tambaqui price (R$/ton)	Frozen tambaqui price (R$/ton)
South				
Fresh tilapia	-0.43	0.04	0.16	0.01
Frozen tilapia	0.04	-0.08	0.01	0.01
Fresh tambaqui	0.16	0.01	-0.33	0.06
Frozen tambaqui	0.01	0.01	0.06	-0.10
Southeast				
Fresh tilapia	-0.93	0.09	0.27	0.02
Frozen tilapia	0.09	-0.16	0.02	0.01
Fresh tambaqui	0.27	0.02	-0.70	0.11
Frozen tambaqui	0.02	0.01	0.11	-0.19
Midwest				
Fresh tilapia	-0.16	0.02	0.04	0.00
Frozen tilapia	0.02	-0.03	0.00	0.00
Fresh tambaqui	0.04	0.00	-0.12	0.02
Frozen tambaqui	0.00	0.00	0.02	-0.03
Northeast				
Fresh tilapia	-0.89	0.09	0.38	0.02
Frozen tilapia	0.09	-0.15	0.02	0.02
Fresh tambaqui	0.38	0.02	-0.82	0.10
Frozen tambaqui	0.02	0.02	0.11	-0.17
North				
Fresh tilapia	-0.19	0.02	0.06	0.00
Frozen tilapia	0.02	-0.03	0.00	0.00
Fresh tambaqui	0.06	0.00	-0.18	0.02
Frozen tambaqui	0.00	0.00	0.02	-0.03

Table E.2. Price slopes of the demand function for whole, cleaned

Quantity consumed (tons/region)	Fresh tilapia price (R$/ton)	Frozen tilapia price (R$/ton)	Fresh tambaqui price (R$/ton)	Frozen tambaqui price (R$/ton)
South				
Fresh tilapia	-1.81	0.16	0.37	0.02
Frozen tilapia	0.18	-0.30	0.02	0.05
Fresh tambaqui	0.66	0.04	-0.77	0.20
Frozen tambaqui	0.04	0.05	0.13	-0.35
Southeast				
Fresh tilapia	-3.26	0.34	0.75	0.05
Frozen tilapia	0.31	-0.61	0.05	0.04
Fresh tambaqui	0.94	0.06	-1.98	0.33
Frozen tambaqui	0.06	0.05	0.32	-0.56
Midwest				
Fresh tilapia	-0.57	0.06	0.12	0.01
Frozen tilapia	0.06	-0.11	0.02	0.01
Fresh tambaqui	0.14	0.02	-0.40	0.05
Frozen tambaqui	0.02	0.01	0.06	-0.10
Northeast				
Fresh tilapia	-3.52	0.23	0.98	0.06
Frozen tilapia	0.34	-0.39	0.06	0.05
Fresh tambaqui	1.51	0.06	-2.11	0.30
Frozen tambaqui	0.08	0.05	0.27	-0.49
North				
Fresh tilapia	-0.53	0.05	0.17	0.01
Frozen tilapia	0.05	-0.09	0.01	0.01
Fresh tambaqui	0.18	0.01	-0.50	0.04
Frozen tambaqui	0.01	0.01	0.05	-0.07

For the income shifter vector, the elements in $\ddot{\boldsymbol{\eta}}_j$ represent the effect of a change in income in R$/month on the demand of the product in kg of fish per family surveyed. However, the elements in the vector $\boldsymbol{\eta}_j$ to be used in the equilibrium model need to be the effect of a change in income in R$/month on the demand of the product in tons of tilapia and tambaqui per region. The steps to convert the units of the vectors are the same presented above for $\boldsymbol{\beta}_j$ but instead of dividing by one million in the first step, $\ddot{\boldsymbol{\eta}}_j$ is divided by one thousand, since the units for income are already the same for $\boldsymbol{\eta}_j$. Table E.3 displays the income shifters used in the equilibrium model. Those results are used for both whole, cleaned fish and fillet forms.

Table E.3. Income shifters of the demand function by region

	Income (R$)				
Quantity consumed (tons)	South	Southeast	Midwest	Northeast	North
Fresh tilapia	1.17	2.19	0.50	2.39	0.47
Frozen tilapia	0.10	0.13	0.00	0.10	-0.01
Fresh tambaqui	0.12	0.99	-0.10	0.21	0.38
Frozen tambaqui	-0.04	0.02	-0.05	-0.02	-0.01

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APPENDIX F. ONLINE QUESTIONNAIRE APPLIED WITH FISH PROCESSING FACILITIES IN BRAZIL

Name: ____Title:____________________

Unit name: ____

City: _______________________________________ Date: ___/____/_____

1 – Which year did this industry unit begin the activity? _____________

2 – What are the main processed fish species and the processing type?

Tilapia

[ ] Gutted

[ ] Fillet

[ ] Others (ribs, chunk, strips etc.) __________________

Tambaqui/Round

[ ] Gutted

[ ] Fillet

[ ] Others (ribs, chunk, strips etc.) __________________

Catfish

[ ] Gutted

[ ] Fillet

[ ] Others (ribs, chunk, strips etc.) __________________

Pirarucu / Arapaima

[ ] Gutted

[ ] Fillet

[ ] Others (ribs, chunk, strips etc.) __________________

Others ___________________

[ ] Gutted

[ ] Fillet

[ ] Others (ribs, chunk, strips etc.) __________________

3 – Where the fish come from (in %)?

Own production ____________

*Buy from other suppliers*__________

3.1 – If fish comes from other suppliers, what is the distance of the main ones?

( ) Less than 100 km

( ) More than 100 km and less than 300 km

( ) More than 300 km and less than 500 km

( ) More than 500 km

4 – What are the buyers of the processed production?

[ ] Middlemen

[ ] Supermarkets

[ ] Fish stores

[ ] Restaurants

[ ] Others _________________

4.1 – What is the distance of the main buyers?

( ) Less than 100 km

( ) More than 100 km and less than 300 km

( ) More than 300 km and less than 500 km

( ) More than 500 km

5 – Do you intend to increase the productive capacity in the next 5 years?

( ) Yes

( ) No

( ) I do not know

5.1 – If the answer of Question 5 is *Yes*, How much is the predicted increase?

( ) less than 25%

( ) from 25 to 50%

( ) from 50 to 75%

( ) more than 75%

6 – Do you sell to other countries?

( ) Yes

( ) No

6.1 – If the answer of Question 6 is *Yes*, what production share is exported?

( ) less than 20%

( ) from 20 to 40%

( ) from 40 to 60%

( ) from 60 to 80%

( ) more than 80%

6.2 – If the answer of Question 6 is *Yes*, do you have plans to increase the exportation share in the next 5 years?

( ) Yes

( ) No

( ) I do not know

6.3 – If the answer of Question 6 is *No*, do you have plans to export in the next 5 years?

( ) Yes

( ) No

7 – How many employees does the unit have?

( ) Less than 20

( ) Between 20 and 39

( ) Between 40 and 59

( ) Between 60 and 79

( ) More than 79

8 – What is the average monthly wage for the employees?

( ) Less than R$ 1000

( ) Between R$ 1000 and R$ 1999

( ) Between R$ 2000 and R$ 2999

( ) Between R$ 3000 and R$ 3999

( ) More than R$ 3999

9 – What are the main problems to sell the processed fish?

[ ] Sanitary barriers

[ ] Lack of buyers

[ ] Default

[ ] Insufficient production volume

[ ] There are no problems

[ ] Others _________________

10 – Check the option that describes better the relationship between the industry unit and buyers?

( ) We sell without worrying, we have a solid and trustworthy business relationship with our buyers

( ) Although we know them, sometimes we personally check the negotiations to make sure everything is going well

( ) In every business we do we always have to make sure that everything happens properly, unfortunately our trust is very low

11 – Check the option that describes better the relationship between the industry unit and suppliers?

( ) We buy without worrying, we have a solid and trustworthy business relationship with our suppliers

( ) Although we know them, sometimes we personally check the negotiations to make sure everything is going well

( ) In every business we do we always have to make sure that everything happens properly, unfortunately our trust is very low

12 – What are the main difficulties to process the fish in the region?

[ ] High operation costs

[ ] Lack of labor

[ ] Environmental/sanitary licenses

[ ] Market

[ ] There are no difficulties

[ ] Others _________________

13 – Do the company work on other activities besides processing?

[ ] Fish farming

[ ] Fish feed, fish oil or fish meal production

[ ] Transportation

[ ] Ice production

[ ] I do not work in any other activity

[ ] Others _________________

14 – What technologies were used in the last 5 years?

[ ] Mechanically separated meat or fish flesh

[ ] Production of Flour or oil of viscera

[ ] Water reuse

[ ] Extraction of skin

[ ] Use of solar energy

[ ] Wastewater treatment

[ ] Others _________________

[ ] I did not used any technology described above

15 – What is your annual processing capacity (ton)? _____________

16 – How much was processed last year (ton)? _____________

17 – What is your average cost of processing of the main product (R$/kg)? _____________

18 – What is the share (%) of each of the items below in the processing cost?

[__] Packaging

[__] Energy

[__] Maintenance

[__] Water

[__] Labor

[__] Administrative

[__] Fish to process

19 – What is the cost of transporting one ton of processed fish (R$/km)?

[__] Fresh fish

[__] Frozen fish

20 – What is the yield for each of the processing forms (%)?

[__] Tilapia whole, cleaned

[__] Tilapia fillet

[__] Tambaqui whole, cleaned

[__] Tambaqui fillet

VITA

Fields: Fisheries and Aquaculture Economics; Econometrics; Agricultural Economics; Social Well-being Programs Economics; Economic Impact Assessment.

Education:

- M.Sc. in Economics, University of São Paulo – USP, March 2010.

  Major: Applied Economics.

  Dissertation Title: An analysis of the racial segregation effects on students test score in the Brazilian elementary school.

  Committee Members: Luiz Guilherme Dacar da Silva Scorzafave; Naercio Aquino Menezes Filho; Elaine Toldo Pazello.
- B.S. in Economics, Pontifícia Universidade Católica de São Paulo – PUC-SP, December 2006.

Complementary Education:

- Undergraduate in History (not finished), Universidade Luterana do Brasil – ULBRA, Brazil. Year of interruption: 2015.
- Short course: Research applications in seafood marketing. (Credit Hours: 34h). Centre International de Hautes Études Agronomiques Méditerranéennes, Zaragoza, Spain (2012).

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Professional Experience:

- **Researcher Assistant**, Department of Agricultural Economics, Purdue University (August 2016 – March 2020).
- **Researcher/Supervisor of Section of Technological Assessment**, Embrapa Fisheries and Aquaculture, Brazilian Agricultural Research Corporation – Embrapa, Brazil (February 2011 – Present).
- **Economic Analyst**, ADDAX Assessoria Financeira (Financial Advisory), Brazil (June 2010 – February 2011).
- **Professor (Microeconomics, International Economics)**, Escola Superior Diplomática – ESD, Brazil (July 2010 – December 2010).
- **Economist**, Fernandes & Terruggi Consultants - F&T (January 2010 - June 2010).

- **Analyst (Backoffice)**, HSBC Bank, Brazil (March 2003 – January 2008).

Other Educational and Work Experience

- Research Projects (coordinator):
    - **Embrapa**: Strategic diagnostic of institutions suppliers and demanders of technology in fisheries and aquaculture – Aquapesquisa, 2012-2013;
    - **Embrapa**: Economic and financial analysis of familiar aquaculture in the state of Tocantins: a model adapted to the local reality to the local rural extension, 2012-2014.
- Research Projects (participant):
    - **Embrapa**: Assessment of social and economic performance of tilapia farming in Brazil, 2015-2016;
    - **Embrapa**: Survey of Management Information of Aquaculture Centers in Brazil, 2014-2016; **Embrapa**: Development of an innovator carrying capacity methodology to estimate the maximum tambaqui production in Peixe Angical Reservoir, 2013-present;
    - **Embrapa**: Development of productive inclusion strategies for small scale fish farmers of the tocantins state based on approach of governance of the global value chain, 2012-2014;
    - **Embrapa**: Technology Transfer for the dairy cattle sector of Tocantins, 2012-2015
    - **Embrapa**: Technology transfer for the consolidation of low carbon emissions agriculture in Tocantins, 2012-2015;
    - **Embrapa**: Strengthening of fish culture as income alternative and diversification of familiar agriculture in Tocantins State, 2011-2014;
    - **USP**: Education observatory (Research group in economics of education created from a partnership between USP and Brazilian Ministry of Education), 2008-2009.

Teacher Assistant, USP, Microeconomics I and II, Statistics courses. 2009.

Professional Memberships:

- Brazilian Society of Economics, Business and Rural Sociology (Sober).
- Regional Economy Council of Tocantins (Corecon-TO).

Languages:

- Portuguese (native language – Brazilian nationality); English; French; Spanish

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