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Aquaculture as a Method to Insulate Fishery Markets from Oil Spill Shocks

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While writing this thesis, I have not witnessed any wrongdoing, nor have I personally violated any conditions of the Skidmore College Honor Code.

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Abstract:

Resource extraction from wild fisheries is and continues to be a behemoth of an industry both in the US and worldwide. Indeed, wars have been fought over such resources, and many communities have become dependent upon the oceans to provide their primary industry. Oil spills are an ecological disaster that serve to uproot these quintessential pillars of these communities, and lead to externalities that are difficult to quantify. As oil spills occur, fishery harvests cease as toxic chemicals infect the water surrounding these communities, effectively leaving them in deep recessions. In this paper, aquaculture is examined as a potential alternative to wild fishing within these communities in order to mitigate the volatility caused by frequent oil spills and other pollution within the ocean. The effects of the Deepwater Horizon oil spill in the Gulf of Mexico are compared to the effects of the recent Sanchi oil spill within China to analyze the effectiveness of aquaculture as an insulating factor that could protect the fisheries industry from volatility due to oil spills.

Introduction

Fishery Regulation Overview

Fisheries management has long been a quintessential issue when determining how best to serve that sector of the economy, as sustainability must be tempered with an understanding of the economic health of small fishing communities. This has led to the US adopting several stances in order to ensure the economic health of this sector while also attempting to protect domestic fishery stock sizes from the dangers of overfishing. This has played out in a myriad of ways, and several papers have been written regarding the benefits and detriments of different fisheries policies. For example, In the case of cod, the Gulf of Maine stock was found in a 2015 estimate to be severely overfished and has led to a change in policy concerning the species. (Caddy) In a new 2014 ten year plan to repopulate the fishery, the New England Fishery Management Council implemented time and area closures, annual catch limits, and minimum size limits on fishermen in an attempt to increase costs on fishermen as well as protect younger populations of cod so that they have the ability to spawn at least once before being caught; however, a few potential issues historically have occurred with many of these policies. (Sumaila) Firstly, time limits on fishermen have had the effect of a "derby fishery" where fishermen are incentivized to catch as many fish as possible during the early portion of the year. (Pudden) This is particularly problematic with cod, which has a one-year breeding cycle that begins in the late winter into the early spring. Because the TAC is not spread over a period of months, vessels are incentivized to all rush at the beginning of the year to absorb as much of the TAC as possible. This increase in effort will lead to large by-catches and could have little effect on the declining populations of cod (amongst other fish) in these fisheries. Another policy that the US has implemented to combat overfishing is the "optional catch share program" which acts similarly to an individual transferable quota. The primary difference being this program requires multiple boats to operate in "sectors" which have their own individual catch limits. These sectors have more freedom over where they can fish as well as what gear they can use to catch species such as cod. These sectors somewhat mitigate the "derby fishery" that would occur from a TAC, as it allows the fishermen in these sectors to access parts of the biomass that are restricted to others. The primary issue with this; however, is that fishermen are allowed to opt out of the ITQ and instead operate as an individual fishermen, allowing them to operate under the TAC. Because fishermen are allowed to opt out of sharing a catch with several boats under the ITQ, it is likely that larger boats will choose to operate on their own (as sector catches are presumably split among the fishers taking part in the group). Because the issue of a "derby fishery" still is allowed to exist, overfishing will likely still occur during the months most critical for the growth of the cod biomass. These examples of failed policies are important to understand in order to ensure a complete picture of the types of costs associated with investment in wild fisheries is understood. These regulatory costs therefore must be understood with the practices that are discussed in the literature.(Pudden)

Literature Review

Deepwater Horizon Background

The Deepwater Horizon Oil spill took place on June 20th, 2010, and remains an example of one of the most dramatic environmental disasters of the last century. The most dramatic moment of this event occurred on April 20th, 2010 when the Deepwater Horizon oil rig exploded due to human error and a failure to follow basic safety measures in the construction of the platform. Other than the direct costs levied upon the BP oil company following the destruction of the platform, death of 11 workers, and loss of millions of gallons of crude oil, the spill itself affected the local community in several measureable ways. The most obvious of these is the direct effect on the fishery population. This has a cascading effect upon the market for seafood products as the supply of these products (especially ground dwelling species) was utterly contaminated by the oil spill, and thus were unable to harvest many of the species for several years following the incident. These direct costs coupled with several other measureable costs to severely negatively impact the community.

The mental health question also appears to be fairly important when considering the implementation of this insulation plan. Indeed, in a study done by Sumalia, it was shown that anxiety over the potential loss of jobs due to the spill, coupled with the uncertainty of the whole situation given that the Deepwater Spill was over the course of 87 days, meant that profound changes occurred within the Gulf coast community. While things like anxiety and other mental issues are difficult to quantify, and thus this particular analysis was done through survey questions concerning the mental health state of both victims of the Deepwater Horizon spill and the Exxon Valdez spill, the effects upon the potential goods baskets that the residents of this area in particular consumed before and after the spill creates an interesting narrative as to how these large scale pollution events affect the local markets within these fishing communities. For example, diets changed rapidly following the Deepwater Horizon spill, as consumption of shrimp in the Gulf coast before the oil spill was nearly three times larger than the national average. Following the spill, there was a great deal of fear among people in the FDA concerning the effects that oil would have on the shrimp, and thus they have made steps to attempt to get people to slow their consumption of the food. This has cause a shift in the culture that otherwise would not have occurred. Interestingly, these issues do not appear to be prevalent in China following the Sanchi spill, as my analysis will show, because the aquaculture industry that so many rely upon in China is insulated from these pollution effects. Thus the level of volatility of the market structure due to oil spills and other pollution will thus mitigate many of these mental health concerns. The measurement of these additional costs is the primary focus upon what most of the literature has focused on for the Deepwater Oil spill.

In this paper, I will use the Deepwater Horizon oil spill and the recent Sanchi Oil spill as an example of total habitat destruction and analyze how the ability to extract resources from these fisheries is affected by the spills themselves. I will propose that an expansion of the aquaculture industry within the US will insulate our current fishery market from the potential damage that oil spills can cause to these facilities.

Costs and Externalities in the Fishing Market

In using this literature to build an idea of the types of costs associated with wild fisheries, one can thus understand how some of the costs are to be calculated; however, in terms of researching types of costs that exist for these wild fisheries, one must also take into account large, economy defining shocks that affect both the fishery stock size and the livelihoods of fishermen. That vehicle for determining this hidden cost of investment in wild fisheries will be oil spills. Upon reading the literature concerning the study of oil spills, several aspects of the way in which spills are measures become apparent. Much of my research has focused on studies regarding the Deepwater horizon oil spill and the apparent effects of that spill on the local economy. Surprisingly, that spill in particular elicited an especially large payout from BP that amounted to 20 billion dollars; however, judging by a study done by Dalton that number may in fact be too low. By calculating the long term damage to different species of fish (and especially mollusks like clams and oysters) the recovery time for such creatures is significantly longer than that of normal migratory fish. (Dalton Et. Al) Furthermore, carbon deposits that rest on the ocean floor have negative impacts of the health of local species for many years to come, as seen by McCrea-Strub when studying the still current effects of the Exxon Valdez spill in Alaska. These effects appear to last far longer than many consider, although the main shock effects of the oil spills have been shown to occur within a three year time period. Interestingly, Dalton also provided a large section of their research to the damage to aquaculture within manmade harvesting pools on the shoreline of the Gulf of Mexico and found that the damage of such a spill was significant, as the spill bled into many of the farmed oyster areas and affected their harvests for the next few years, although ultimately the damage done to the aquaculture was far less than that done to the wild fishery in that report. This is justified because aquaculture cultivators are able to somewhat protect their stretches of aquaculture through the use of nets and other barriers that can block some of the incoming oil, thus oil spills still do less damage in this context.

The power of these specific oil spills is that it provides a framework with which to measure whether significant investment in aquaculture can in fact promote an economy that is more resilient to the externalities associated with oil spills. Thus, to provide a suitable comparison with the damage caused by the Deepwater Horizon oil spill, I will thus use the recent Sanchi Oil spill in China to provide a view of how economies heavily invested in aquaculture can benefit from reduced impacts of these oil shocks. (McCrea-Strub) Certainly the paper written by Giudici, can provide some view into how much damage this shock did to the immediate Chinese economy, as Giudici provides stock data concerning the effects on Chinese markets following this seemingly devastating oil shock. Obviously the challenge with using this data and study when comparing the effects of this spill with Deepwater Horizon will be that this is a very narrow way to view damage caused by the spill, and thus it will also be important to use some of the cost measuring studies to estimate the damage caused by this spill in the Chinese context. Using the literature that describes measuring cost of the Deepwater Horizon oil spill will thus be comparable with the noted longer term effects that this spill will have on Japan (as it is an economy much more invested in wild fisheries than China), and will also serve as an excellent example to hold next to the noted effects that the spill will have on China. (Cao Et Al.) In creating this analysis of whether Chinese aquaculture will indeed dramatically shrink the damage caused by large scale oil spills, and understanding of what some of the major externalities and costs of aquaculture are.

Sanchi Oil Spill

My research into the Sanchi oil spill has yielded interesting results, as I found this spill to be fairly comparable in size to massive US spills like the Exxon Valdez and Deepwater Horizon spills of the past. This is important to note as comparing these spills and the response to these spills is a primary resource in the discussion section of this paper since literature already exists describing the impact of this spill on several Chinese stocks is still being felt a year later. (Seeb) This will certainly be comparable with the effect on US stocks that are heavily impacted by the fishing industry following the Deepwater Horizon oil spill.

Another difference between the Sanchi Spill and the Deepwater Horizon spill outlined in the literature is the type of oil that oozed out into the ocean, as the more recent Sanchi spill was a case of heavily refined petroleum that is less dense than the crude oil that flowed into the Gulf of Mexico during the Deepwater Horizon spill. Because these spills themselves were so different in terms of the actual type of oil that was spilled (and scientists are still unsure of exactly how harmful the lighter, more refined petroleum will be on the local environment) it would be difficult to quantify the costs of these spills by the environmental damage caused by each one, and thus I will be primarily focusing on the effect each of these spills had on the stock market and the affect that each had on local fishing industries. Because China is far more heavily dependent on aquaculture (as heavy investment into that industry began in the 1980s and has continued until now) I expect these effects to be quite different, and certainly according to Gill and Sumaila's respective pieces on the economic impact of these oil spills on each economy separately, I can thus use this to extrapolate the reasoning to be tied to this aquaculture investment. (Cao)

Aquaculture

When analyzing the Chinese aquaculture market, one must also take into account the massive growth and investment in the industry that simply doesn't exist to the same extent in the US. Indeed, the Chinese began investment into this form of cultivation as early as the early 1980s, and the technology and techniques used in these manmade lakes and ponds has only served to improve. In fact, according to Cao, these early Chinese aquaculture facilities came with several measurable environmental issues, as the pools would damage the surrounding land and ecosystem, lead to genetic stagnation within the fish population, and come with large amounts of pollution. Although the potential risk costs of these aquaculture pools were quite high during the early years of the practice, recent Chinese efforts to continue to grow the aquaculture industry has come with a great amount of focus on sustainability. These new aquaculture pools rely primarily on "hardy" species of fish that are resistant to mutation in order to minimize that risk in particular. The new Chinese model outlined in Cao's piece also sheds some light on how these externalities have largely been mitigated with more modern methods of aquaculture. One such way is through a different system of management, where rather than large government oversight running the industry as a whole, it has since become rather decentralized in order to promote management that prevents local ecosystem damage. This shift is significant, as it reflects how aquaculture would likely be taken in the US, as the government does not run these large operations in the same way as China. This means that decentralization of these plants would already be a factor, and thus the information taken from Mendelssohn piece is extraordinarily useful in imaging how an expansion of the US system of aquaculture would be done. It also suggests that US investment in aquaculture would not see many of the externalities experienced in the earlier days of China's investments, as the US industry would already be working from a position where the "one size fits all" issues of China would not be repeated. The primary difference between the US shoreline style of aquaculture and the Chinese model that is mostly built upon manmade lakes and ponds. This would lead to the expectation that American style aquaculture is still just as affected by oil shocks as many of the wild fisheries in the context of the Deepwater Horizon spill, as the oil can still seep into these areas and negatively affect the yields of these aquaculture firms. What my difference in difference will show is thus that the Chinese model of aquaculture in free standing structures is far more apt to resist oil shocks than the aquaculture that is currently existing in the US. Furthermore, this example of the Chinese aquaculture is a little different from the American context; however, as most current American aquaculture is based on shorelines rather than in manmade lakes and pools (although these do exist in the US) this poses a particular challenge to further investment in the American aquaculture industry; however, with new measures of the type of long term damage done to these fishery communities by oil spills, the less risky option would certainly be investment into the Chinese model of aquaculture, as these risk factors can be mitigated. (Cao Et. Al)

Another aspect to consider when viewing the effectiveness of aquaculture as a method to insulate the fishery's industry from the damage that could be caused by oil spills, is to consider the potential externality effects that aquaculture can have on both local wild fisheries and the consumers of aquaculture products. As outlined by Cao, aquaculture more generally is examined for these externalities and whether they remain significant given advances in technology since the 1980s, when aquaculture first began to gain traction as a sustainable method to produce fishery products. In this paper, the primary ways in which aquaculture can be destructive are examined to be habitat destruction when building the physical plants themselves, removal of waste from these plants, potential genetic deformities that can arise from inbreeding within aquaculture facilities, and the potential for diseases to spread among aquaculture species populations due to their enclosure. These points are important to consider when viewing the costs and benefits to transitioning the current US fishery market into aquaculture to insulate the market from oil shocks. The first of these pointed raised by Cao is the potential habitat destruction due to the building of the physical plant in the initial aquaculture construction. This is a primary concern for inland aquaculture facilities, as certain species require much larger areas to be converted into these aquaculture “pastures”, especially species such as carp and salmon. These larger spaces means that potentially large areas of wilderness must be converted in order to create these facilities. This externality in particular has been document to be less serious than in years past when China was first beginning to ramp up its own aquaculture production, as \ habitat destruction was common during the early stages of Chinese aquaculture growth. This has largely been mitigated; however, as more sustainable methods of construction as well as more sophisticated plant designs have allowed for this externality to be kept to a minimum.

The removal of waste from these facilities has also been posed as a potential externality in the construction and expansion of aquaculture facilities; however, as seen in Cao’s work, China has found uses for this waste as well, in creating “fishery waste balls” to be utilized in other methods of fishery production or in the creation of fertilizers. These uses found for this potential externality mitigate the effect that it could have given irresponsible waste management. Thus, the two primary challenges facing Aquaculture today are genetic deformity, diseases, and genetic diseases among fishery populations within these Aquaculture facilities. These have been the primary concern from critics of aquaculture, as the potential damage that specimens of fish carrying genetic diseases could have on both humans and wild fish populations given escape are serious. In a paper by Giudici, these potentially damaging effects are made clearer as early in the development of Chinese aquaculture the issue of increasing amounts of mercury and other harmful materials found in the aquaculture produced fish raised several health concerns about consumption of goods produced from these facilities. It stands to reason that there is a certain fear surrounding consumption of aquaculture products, especially in the US as shown by Cao, who catalogued the public perception of aquaculture products and found that there were wide misconceptions concerning the consumption of these products. Indeed, many people in the US especially seem to be fearful of the health detriments of eating fish produced in these type of facilities. As the US currently imports large amounts of seafood from China (many of it raised in aquaculture) these fears of disease does limit the reach of the aquaculture market to serve all US consumers. Furthermore, environmentalists fear that the release of aquaculture raised species into the wild would serve to infect the healthy wild populations with these potentially catastrophic genetic diseases.

Given these fears of disease for humans as well as wild fish communities, one can look at the paper written by Cao to see how improvements in technology has allowed the damage caused by these potentially harmful effects of aquaculture has largely been mitigated. Firstly, the fear that aquaculture species would be released back into the wild population is really more of an issue concerning facilities that are still connected to major waterways. Namely, current US aquaculture facilities, as nearly 75% of Chinese aquaculture facilities are free-standing and do not connect to rivers or oceans, instead being raised in manmade ponds. This eliminates many of the potentially damaging effects that aquaculture can have on wild populations, as the species lack the ability to escape the facility and connect with wild populations. Concerning the safety of human consumption of these products, technology and methodology has come quite a long way concerning the ways in which these facilities are both constructed and run to ensure the least chance of these issues occurring. Scientists have been able to find cures for many fish diseases for this very reason, one famous recent case was the discovery of a cure to a genetic disease affecting shrimp where they would not grow beyond an adolescent size. (Cao) These changes in technology has allowed for these aquaculture to become sustainably healthier in the years since China began aggressively pursuing and expansion of the Aquaculture market.

China's expansion of the aquaculture market must thus also be viewed among its costs and benefits, as outlined by Cao, as China's drive to build up aquaculture has seen the commercial fishing industry shrink considerably as the new system seems to be a sustainable method of feeding the Chinese populace and constitutes a significant portion of their food economy today. As the fastest growing food industry in China, aquaculture continues to be relied upon in order to both sate domestic fishery demand as well as provide significant amounts of seafood to be sold on the international market. This shrink in the commercial fishing industry has been mitigated by a significant boom in this aquaculture market, and thus job growth within China is not severely adversely affected by this investment, as fishermen are able to largely convert to working in these large aquaculture facilities.

Costs on Trade and Externalities

Another consideration to make regarding the Sanchi Oil spill is the effects of trade between China and Japan following the spill itself, and the oil has severely hampered the local fishing economy of Japan. In a paper by Islam, it is thus discussed how these types of externalities can impact the trade relationship between nations when this type of environmental externality occurs. (Islam Et. Al) Potential damage to trade relationships due to this type of externality could also be supposed as a potential cost consideration when viewing the impact of these oil spills on fishing communities. Indeed while there has yet to be a paper written on how this specific oil spill has affected Chinese and Japanese trade policy, one can use examples of how other nations interact in similar situations to predict how this spill will lead to heightened costs for this industry. These trade costs are yet another piece of measurement of the damage caused by these oil spills, and will be wrapped with many of the metrics used in the literature for measurement of the long term damage caused by Deepwater Horizon. This can viewed by Caddy piece which analyzes the effects upon trade of fishery resources following the Deepwater Horizon spill, and creates a case for how each individual type of resource is affected by the oil spill itself. The useful piece of information from this source in particular is the cost analysis regarding how long it would take each type of species to become viable to fish once again after the spill. This analysis found that species that are more sedentary, such as mollusks, are much more affected by the oil shock than migratory species. This distinction is also important to consider as the Sanchi spill was refined oil, thus the effects upon sedentary species is lessened, although the lighter petroleum will certainly adversely affect migratory species, thus the usefulness of this analysis in the context of Sanchi is limited. Although this literature analysis of the costs upon the resource itself is important to consider, especially in regard to trade relationships, this difference in the type of spill will certainly need to be considered in my comparison.

The literature has supplied both a historical context to the issue of fisheries management as well as further explanation into how costs are essentially calculated for this industry in particular. Most useful for my purposes will be these cost models as they supply me with different ways to measure the long term damage that oil spills can have on fishing communities. An understanding of this damage is essential for measurement of this cost in both the American and Chinese context, as an analysis of how these markets respond to environmental shocks will be my primary research question. Furthermore, and understanding of how trade impacts many of these costs will also be paramount in exploring the costs on local fishing communities that this oil transport necessarily brings. Through use of my two examples of major oil spills, I will answer this question of whether significant aquaculture investment will indeed reduce this cost and better serve local fishing communities in this context of massive oil spills which can suddenly threaten both fishery stock sizes and the livelihoods of fishermen. This question of aquaculture as a method to protect against oil shocks, which does not exist in the literature, can thus be answered through the cost analysis of oil spills present in the literature as well as the purported costs associated with fisheries management in both the US and China.

Analytical Framework

Data Collection

Upon analysis of my US Gulf fishery data, I was able to collect statistics from the NOAA which is a government agency that collects yearly statistics regarding US fishery landings, catch rates, and aquaculture collection rates throughout the US. Usefully, the NOAA also breaks down data by state and thus makes it intuitive to collect the data on the various Gulf economies that were adversely affected by the Deepwater Horizon Oil spill. For all of these variables I will be using a difference in difference regression to prove that the spill adversely affected these economies by comparing the Gulf fisheries to Atlantic fisheries across the same time period. In addition to this regression I ran a difference in difference regression regarding these wild Gulf fisheries across the same time period as aquaculture extraction throughout the late 2000s and early 2010s. To collect my Chinese aquaculture and fisheries data, I collected this from the World Bank which supplied me with data up until 2018, which was important as 2018 is my only year where the Sanchi Oil spill has affected my target market.

Model

Firstly I ran a basic regression using a dummy variable which was the existence of the oil spill in general. This dummy variable was set to zero in the years preceding 2010 and one in the years afterward, moving up to the year 2013, as by that point officials claimed that the primary shock of the oil spill had already been felt. My primary model for all of these analysis is as follows:

$$\mathbf{Y = \beta_0 + \beta_1 O_{it} + \beta_2 T_{it} + \beta_3 O_{it} T_{it} + \varepsilon_{it}}$$

This difference in difference model allows for me to control for many of the potential additional factors that may affect fishery extraction in all of my examples, as I use the two oil spills (Deepwater Horizon and Sanchi) as dummy variables during the period that the oil spill affected fishery and aquaculture harvests.

Results:

The regression was performed for all Gulf States to determine if the oil spill had an effect upon fishery extraction within the Gulf, which is something that has already been proven by the literature; however, I was able to utilize the data in order to prove that the aggregate shock of the oil spill on the wild fishery industry negatively impacted the US economy as well as negatively impacted aquaculture in the region. My results for this first difference in difference analysis are as follows:

Gulf Fishery	Coefficient	Standard Error	T	P-Value
Deepwater Horizon Spill	**-216358.3**	**91748.64**	**-2.36**	**0.031**
Atlantic Fisheries	**0.4525817**	**0.3552425**	**1.27**	**0.220**
Interaction Term	**-292981.9**	**58477.5**	**1.79**	**0.016**

As one can read from this first difference in difference analysis, Gulf fisheries in aggregate were heavily negatively affected by the Deepwater Horizon oil spill while my control group (Atlantic Fisheries) remain unaffected by the oil spill itself. This first analysis, though it does not prove anything new, as the literature clearly understands that the Deepwater Horizon spill did indeed have a serious impact upon the ability for fishermen to extract resources from this affected area. Indeed, as one can see, there is a large negative coefficient when the dummy variable of the Spill is applied with a rather low P-value for both of these terms. The control variable is, as expected, unaffected by the oil spill, which may suggest that these facilities are already running at full capacity, and thus cannot expand their production to respond to the oil spill in the Gulf.

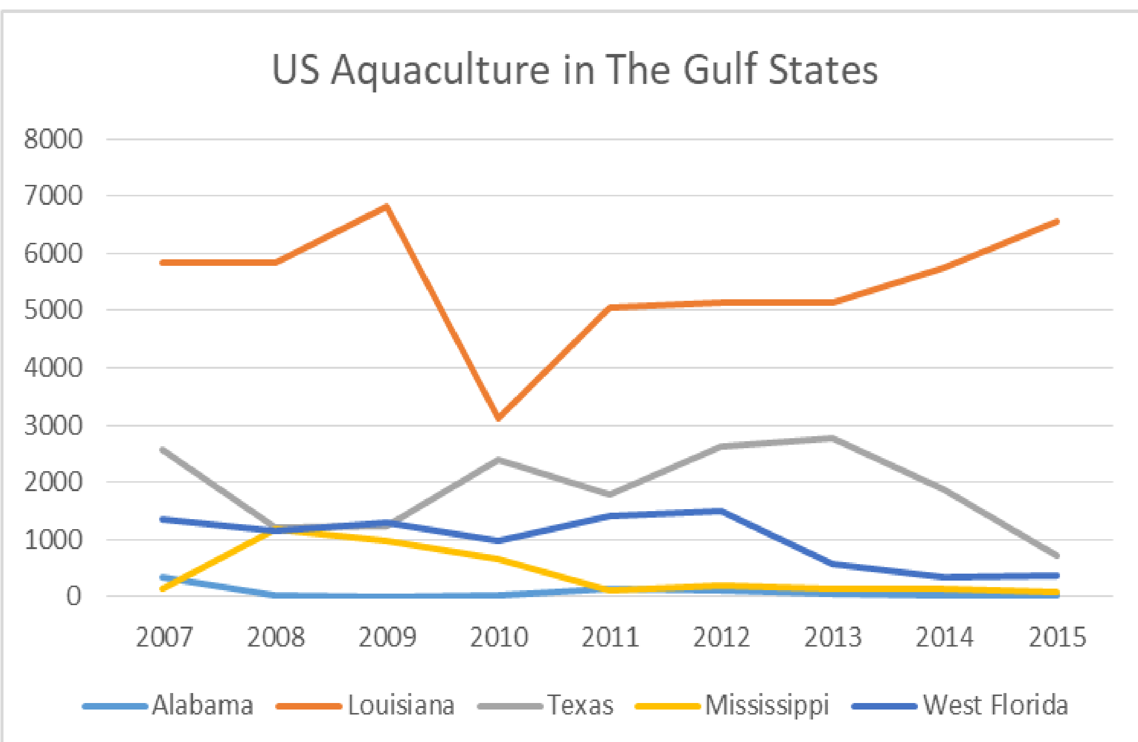
Louisiana Aquaculture	Coefficient	Standard Error	T	P-Value
Deepwater Horizon Spill	**-2470.023**	**772.5456**	**-3.20**	**0.019**
Atlantic Fisheries	**0.5421416**	**0.3991345**	**1.27**	**0.220**
Interaction Term	**-5991.083**	**1550.107**	**-3.86**	**0.008**

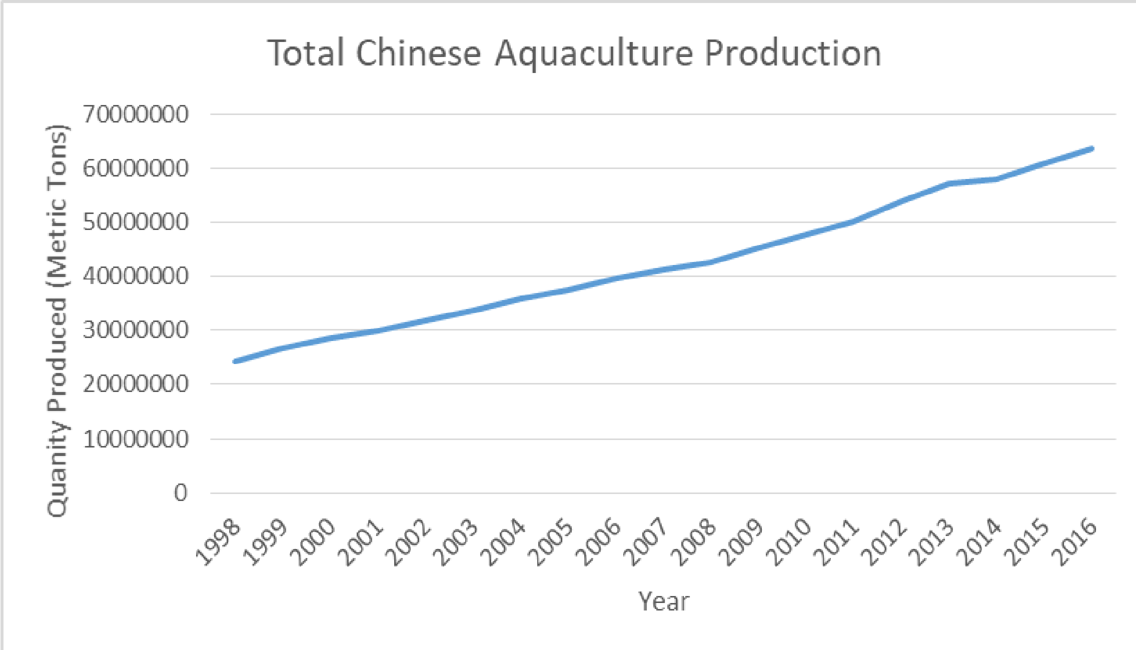
This second regression is important as it deviates from my initial hypothesis that aquaculture in general is insulated from the potential damage that could be caused by oil spills. This difference in difference analysis, still using the Atlantic fisheries as a control variable, suggests that US Gulf fisheries were indeed still affected adversely by the oil spill in question. Though this effect is stated in the literature, it is rather surprising that Louisiana aquaculture is affected to this extent by the pollution caused by the oil spill. Indeed, these low p-values suggest that the effect of the oil spill is significant while the control remains largely unchanged. The reason Louisiana was selected as the independent variable for this regression is the fact that US aquaculture in the Gulf is currently most prominent in that state. Furthermore, the spill itself most prominently affect Louisiana due to the proximity to the state itself. The reason aquaculture in this state was so heavily affected is because most US aquaculture is situated along coastlines in areas of the ocean that are roped off to raise certain seafood's, most prominently sedentary species such as shrimp, oysters, and clams. These species are not only more heavily affected by spillage of crude oil due to its tendency to sink down into the bottom of the ocean, but because US aquaculture does not currently have many protections to separate these aquaculture species from the potential of infection by these oil spills, this regression proves that steps since 2003 (when the last study to cover this issue has been conducted) have not been taken to defend against this issue.

China Aquaculture	Coefficient	Standard Error	T	P-Value
Sanchi Spill	**7402938**	**8932397**	**0.83**	**0.419**
Chinese Fisheries	**-273675.4**	**86456.1**	**-2.34**	**0.013**
Atlantic Fishery	**-159.91**	**37.32157**	**-4.28**	**0.001**
Interaction Term	**. 450202**	**.1924071**	**1.79**	**.1**

The final (and most interesting) difference in difference analysis that was run looked at Chinese aquaculture facilities and their ability to produce fishery products following the recent Sanchi oil spill. Furthermore, I ran a difference in difference analysis of the effect of the spill on other Chinese wild fisheries to establish that these spills do indeed heavily mitigate the ability for fishermen to extract resources from these areas. Unsurprisingly, the Sanchi oil spill is met with a large negative coefficient when regressed with overall Chinese wild catch numbers, with a low p-value to establish significance. This large negative coefficient is not surprising and reflects a similar coefficient seen in the Gulf wild fishery example. The number itself is quite high for the relatively small amount of time that the spill has affected the area, likely because the type of oil spilled in the Sanchi spill was more refined than the oil seen in the Deepwater Horizon. Though scientists have not come to a consensus regarding the effects that this type of oil may have on the species in this area, many believe that because the oil is lighter, and thus doesn't sink as much as crude oil would, the short term effects would be more powerful than would be expected from a crude oil spill. Given that expectation, the most interesting variable that I have regressed in this example is the Chinese aquaculture variable, which reflects the total amount of aquaculture products produced in China by tons. The growth of this industry compared to the Gulf aquaculture is shown graphically below in figure 1. In this regression, both the interaction term and the dummy term is shown to not be significantly affected by the oil spill itself, which suggests that the type of Aquaculture practiced in China is this insulated type that is largely protected by the externalities of these other ocean extraction and transport industries. Indeed, the lack of significance confirms my hypothesis that aquaculture can be used to mitigate the volatility and damage potentially caused by catastrophic oil spills.

Figure 1





As one can see from the above figures, the Atlantic states were largely unaffected by the Gulf oil spill, as my difference in difference regression proves; however, the effect on aquaculture is still present in the American context. This affect is likely due to the fact that much of the aquaculture that exists currently in the Gulf are merely extensions of the ocean rather than free standing aquaculture facilities, like would exist in China. This is reflected in my difference in difference model, as the effects of the spill upon US aquaculture in the area is certainly negative due to their location upon the ocean. That being said, these regressions also paint in interesting picture into the wild fishery market, as lack in fishery catch rates in the Gulf due to the oil spill does not appear to coincide with increases in the catch rates of these other fisheries. As can be seen in figure 2, this drop in supply of fishery products from the Gulf fisheries is not met with an increase in supply from Atlantic fisheries. This is because these other fisheries are already operating at full capacity. This would suggest that many of these fisheries are operating at full capacity, as the stock size that can be extracted cannot increase further without doing damage to the overall stock size within the fishery. Indeed, it would appear that these markets are operating at fairly full capacity in general, as evidenced by their relatively slow growth rates except in the case of large drops in productivity due to the oil spill shock. The American context of this type of shock is thus represented by the difference in difference models to show that oil shocks do indeed negatively affect the growth rate of these various affected fisheries and don't coincide with other market forces that would change catch rates in unaffected areas. Indeed, it is interesting that these unaffected areas seem to have no response to the oil spill, as a massive decrease in the supply of wild fishery products coincided with the spill, which could not be filled by these other fisheries as they were already operating at full capacity.

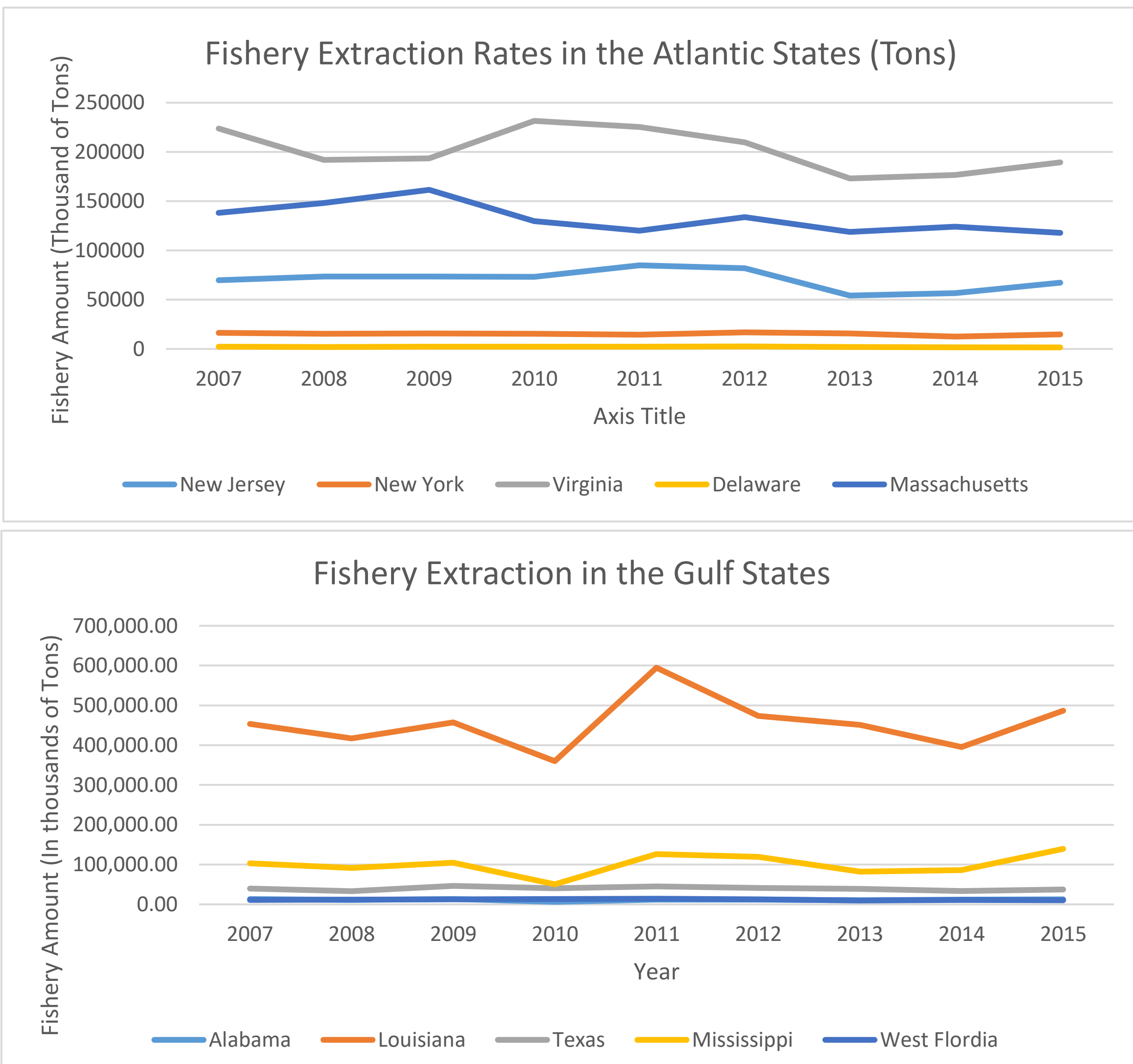


Figure 2

This difference in difference analysis thus proves that while the oil spill did indeed serve a negative impact on the Gulf economies that were subject to the oil shock in question, the aquaculture in these areas was likewise affected negatively by the oil shock. This suggests that the type of aquaculture that this study recommends is likely the type that is used by China, as much of their aquaculture is not directly affected by the areas that would be subject to oil shocks, I expect to see this when difference in difference analysis is done in the Chinese context under the Sanchi oil spill, though for the purposes of this draft, an analysis of the American fisheries market is most apt for this difference in difference analysis. The p-value (p=.1) shown when comparing the aquaculture statistics to fishery statistics when considering the effect that the Deepwater Horizon oil shock had on the fishery market is far too high to suggest any difference between American aquaculture performance within oil shocks, although again, my expectation is that Chinese type aquaculture is an important consideration when viewing the affect that oil spills can have on the fishery market.

The causal relationship of the growth of the Gulf fishery industry and the oil shock is evidenced by this difference in difference analysis between the fisheries that were unaffected by the oil shock (that being the Atlantic fisheries) and those that were affected by the shock itself in 2010 onward. This analysis shows a negative impact upon the growth of these fisheries in the Gulf that was not experienced by the Atlantic fisheries in the same way, and thus a causal relationship between the Deepwater horizon oil spill and the decrease in fishery yield is apparent (p=.03). Indeed, it would appear that this oil spill shock in particular is responsible for the decrease in growth that can be seen in graph 1. The interaction between this spill in particular and the aquaculture facilities within the Gulf must thus be analyzed further when considering the Chinese example in a later draft.

Measurement of the cost upon the Gulf fishery is likewise an important aspect of this analysis in determining the overall costs associated with these oil shocks on the fishery industry. The most obvious way to measure this cost is through use of the determined payout that BP was forced to pay in order to account for losses to the wild fishery community. This payout being 62 billion dollars which BP was forced to pay both in fines and to the public direct affected by the oil spill. These costs must be considered when measuring the effects of the externalities associated with oil spillage upon the fishery economy. Indeed, as stated above, previous studies have determined that this cost from the payout is far too low, as it fails to account for mental health issues caused by the spill which turned the fishery economy on its head. Thus, the use of the difference in difference analysis allows me to measure the causal effects of the oil spill during the time period 2007-2015. IN this analysis, an overall cost of the spill in lost revenue seems to be closer to 100 billion in damages to the local community as well as governmental fines. This cost can thus be levied as the overall cost to the fishery following the oil shock due to the lost revenue in the short term and the loss of demand for fishery products from the Gulf after the spill in the long term. Dietary changes have been recorded to have occurred in the Gulf area as widespread fear of the effects of oil-polluted seafood upon their health. Consequently, health concerns throughout the Gulf are another aspect of this externality of the oil spill that must be considered during later analysis in my next draft.

The primary information that I have been able to gain through my difference in difference analysis of the US Gulf fisheries sector is both proving a causal relationship between the oil shock and the decline in fishery extraction for the year 2010. Although the recovery seems to have been quick, the overall market effect upon the fishery products is significant, as previous studies have shown dietary changes in the American population due to fears of health risks associated with consumption of potentially oil contaminated food and products. This other costs are directly impacted by the oil spill in general, as fish die and the total extraction rate decreases significantly. In later drafts, I will include these cost projections into my difference in difference model to accurately measure the costs associated with these oil shocks now that I have proven that they do indeed negatively affect the affected fisheries while not having an impact upon other fisheries that don't experience the shock, even though overall fishery supply does indeed drop following these oil spill disasters. In later drafts I also aim to prove that the Chinese model of aquaculture is effective in mitigating these risks of oil spills as free standing aquaculture facilities are unaffected by ocean oil spills as the oil cannot physically attack the fish species within the aquaculture facilities. This will be a comparison of both the Chinese and US models of fishery management, aiming to prove that the Chinese model mitigates these risks of shocks and thus is less volatile than the American fisheries market. In addition to that proof this data of other fisheries not responding to supply deficits due to oil spill shocks suggests that American fisheries are extracting at full capacity, and thus a shift into aquaculture to feed demand as population grows will likely be inevitable, as other countries have indeed made this investment. This Chinese question, through use of the Sanchi oil spill as a case study will address these questions and hypothesizes.

Because my primary model was a difference in difference analysis, issues of omitted variable bias are not applicable as I controlled for these variables through the establishment of my dummy variables. Because the actual data set was rather small, use of these dummy variables was necessary as I had only aggregate samples of total catch amounts during periods of oil spill. Multicollinearity is not an issue in this model because the total number of variables in my difference in difference is quite small, and thus the potential issue of multicollinearity is solved because of this lack of extraneous variables. This was the primary advantage to using the difference in difference analysis.

Discussion:

Aquaculture thus is potentially the investment that governments and individuals could make to mitigate the adverse effects of volatility due to oil spills. Indeed, investment in the practice does seem to have been wildly successful in China in creating an industry that is insulated against this potential ill; however, one must carefully consider the implications of this transition. Currently, working as a fishermen is one of the most prevalent jobs within the Gulf area, thus a transition into aquaculture would certainly need to consider mitigating the effects of displacement for these workers. An analysis of how exactly inland aquaculture could be implemented is beyond the scope of this paper, though as one can see, inland aquaculture does appear to be a much more stable method of fishery extraction in terms of limiting the volatility due to oil and other pollutants. The Chinese model for aquaculture also merits further study into the potential externalities that inland aquaculture can produce, although many of these externalities that were especially prevalent in the 1980s and 1990s, such as diseases spreading within these aquaculture facilities, have been largely cured or mitigated. The market for wild caught fish will obviously still exist within the US given this increased investment into aquaculture facilities, as the data suggests that wild caught fisheries are already operating at full sustainable capacity or sometimes beyond that. This suggests that with a growing population throughout the world as the demand for seafood increases, aquaculture may not only be our solution to price volatility due to pollution, but also price volatility as the demand for fishery products continues to increase. Our wild fisheries are a renewable resource if harvested responsibly, and thus aquaculture is furthermore a way to increase our overall supply of fishery products while also mitigating the damage caused to the market due to pollution and oil. Furthermore, trade of fisheries products is another issue that aquaculture seeks to solve. Indeed, the excess supply of fishery products that can be generated through aquaculture represents an additional good that the US could feasibly trade internationally. As China has transitioned its aquaculture industry to create tradeable resources, price volatility in terms of trade would largely be mitigated through this aquaculture investment.

The potential costs to trade also enter into this discussion as the oil spill externality affects beyond one single national entity. Indeed, polluted waters do present certain health risks when harvesting species from these fisheries, and thus heavy pollution and oil spills can create a product that is insufficient to sell on an international market. This creates additional volatility, as seen by Fernandez, as countries with different food safety standards would be affected by certain pollution shocks that others do not bear. While large, catastrophic events such as the Deepwater Horizon Spill does create a scenario where extraction of species themselves becomes difficult, small pollution events have been proven to lessen the quality of fishery products, and thus these smaller spills may disqualify these fishery products from these international markets. Additionally, there are many adverse health effects that fish taken from heavily polluted areas can pass onto consumers, creating additional costs onto these externalities. The long term loss of consumption seen by Austin in the Deepwater Horizon spill is catalogued as public perception that the fishery products are far unhealthier than usual, thus decreasing overall demand for these products. Interviews taken from residents in the Gulf area seem to confirm this hypothesis, as dietary habits changed in the local fishery communities seen by Austin's study on the effects of the spill on the local community. This radical shift in the culture of these coastal communities should also be considered as an externality cost of these oil spills, and through investment into aquaculture, many of the mental health issues associated with anxiety over the loss of use of a fishery area can be mitigated through this added security. Furthermore, aquaculture, if raised in a responsible manner, is perceived as healthy for human consumption by the general populace, shown by Cao. This is proven by the growth of the Chinese aquaculture market as health issues associated with aquaculture have been slowly eliminated through discoveries of new technology. Thus, these additional health externalities that would normally be associated with aquaculture are largely mitigated while the health issues associated with eating polluted fish are only seeming to increase, especially in highly polluted areas like China.

Obviously, some displacement will occur within these communities as the fishery economies shift to aquaculture; however, this is a gradual process, much like it has been in China, and thus I would advocate to begin new policy in this realm by incentivizing the creation of aquaculture plants rather than try to shrink the current US fishing fleet. Regulations such as that often do not work, as can be currently seen by China's illegal fishing problems. These aquaculture plants would thus provide a new industry to eventually take over many parts of the wild fisheries industry, as farm raised fish can be produced at a much lower cost than many wild caught species, especially when an event that shocks the fishery stock occurs in the open ocean. The cultivation of certain species that Americans consume in large numbers, such as shrimp and oysters, would be important building blocks in this aquaculture investment, as these sedentary species can be mass produced at a far lower startup cost than other species of sea life. Obviously a market will still exist for wild caught seafood, as public perception has be documented to reflect the belief that wild fish are both slightly healthier and taste better. Although current pollution and oil spills draws many of these health beliefs into question, the element of taste for these products will allow wild fishermen to continue practicing their trade, though likely in much smaller numbers. Additionally, as the price of wild seafood is expected to increase due to these pollution and oil concerns coupled with long standing practices of overfishing means that wild caught fishery products will likely turn into luxury goods. Indeed, these two industries can coexist; however, investment in aquaculture would certainly lead to a far more price stable fisheries market.

Policy Discussion

As my difference in difference proved, the US method of conducting aquaculture will not achieve independence from oil spill and pollution externalities caused by these various other oceanic extraction industries. Indeed, it would appear that the US current model of aquaculture implementation is not suited to account for these potential market shocks. Thus, encouragement to invest into inland aquaculture would certainly allow this industry to expand while finding independence from oil spill externalities. As China has shown, the overall productive capacity for fishery products only serves to expand following this investment, and the US can take several lessons from the Chinese implementation of the technology in order to mitigate many of the externalities experienced by China in the 1990s due to this shift in the fisheries industry. This policy would primarily be concerned with establishing incentives to create these aquaculture facilities, although strict government oversight and micromanagement of the industry can serve to be detrimental. In the Chinese example, the government employed a "one size fits all" method of regulating these facilities without consideration for the species or the local environment where the facility was located. This meant that some species, such as shrimp, were being managed in the same way the Chinese government was facilitating growth of carp facilities. This led to disease being spread among these aquaculture populations and harmed the genetic diversity of the offspring of these farm-raised fish. This deteriorated the quality of the aquaculture produces while also creating several serious externalities, especially in instances where fish with genetic abnormalities or diseases were able to be reconnected with wild populations. In many ways, this did more harm than many of the oil spills studied for this paper, and thus the US, in implementing inland aquaculture methodology, would certainly need to account for these potential effects. Two factors have mitigated these adverse aquaculture effects within China today. The first of these is the fact that technology and understanding of the lifecycles of these species has simply improved. We have new ways of treating diseases within these fishery populations and the government has instituted strict regulation upon the ability of those to take fish from these facilities and release them into the wild. The second reason these externalities have largely been mitigated is the fact that the Chinese government has since taken a more "hands off" approach to aquaculture management, instead allowing facility owners to make decisions for the health of the aquaculture species depending of local circumstances. These two factors would need to be instituted into potential American aquaculture policy as the government could incentivize the creation of this industry, insulated from the ravages of ocean pollution and oil spills.

Thus, the primary benefit of supporting the growth of the US aquaculture industry is that it would allow the US to expand the ability to produce fishery products in an age where wild fisheries are already operating at capacity, or beyond capacity in some cases. The added benefit of an expansion of the aquaculture industry is the fact that this expansion into the aquaculture realm allows for a stable alternative to wild fisheries, which can be affected by price volatility due to oil spills and pollution. Currently, China is beginning to phase out large segments of their wild fishery economy in favor for an expanded aquaculture base, to the extent where, should the latest five year plan be realized, wild fishery harvests will be cut by reducing China's wild fishery operations by 15% while the Aquaculture industry continues to grow. This is based on a set of circumstances in China where overfishing since the 1990s has left many areas in the South China Sea with depleted stock sizes. Though the US is not experiencing this problem to the same extent (China also has pledged to more heavily enforce laws against illegal fishing in the future), a growing demand for fishery products will eventually make this aquaculture transition necessary if prices are to remain stable.

The type of investment and subsidies is also important to consider when thinking about how the US could properly implement policy to expand inland aquaculture facilities throughout the Gulf and other fishery communities that are adversely affected by oil spills and pollution. Given the Chinese model, there are several lessons that one can take to both amplify the given strengths of Chinese aquaculture while avoiding potential weaknesses that one can observe through their models. In the paper by Cao, one can clearly see these policies play out through recent Chinese history to paint an image of how these policies both succeed and fail. Primarily, what the US should avoid in incentivizing the creation of these facilities is excessive micromanagement of these facilities, as China has learned that the productive capacity of inland aquaculture facilities as well as the extent of externalities of these facilities is both increased and decreased respectively. This is not to say that regulation is necessary in expanding this industry throughout the US, as many externalities associated with inland Aquaculture are largely tied to negligence on the part of the facility managers, as releasing potentially genetically altered specimens of a species into the wild can have disastrous consequences for local species. Establishing regulation to reflect the differences in circumstances as well as species differences will also be important in ensuring the aquaculture facility can run smoothly and avoid the “one size fits all” problem experienced in China as they increased their productive capacity in this industry. The structure of the US economy is also such that many of these facilities would be privately owned, thus the establishment of incentives would likely be the most effective way to ensure the growth of this industry for the future of the US fishery market.

Current US regulatory policy within wild fisheries is, as explained above, a combination of several different sorts of measures, from strict regulation to TAC policies. These solutions are often costly to enforce or easy for fishermen to outpace in order to keep fishery production high, thus aquaculture represents an opportunity to expand outward into an industry that is ostensibly more easily regulated. By centralizing fishery operations into specific facilities, as China has done with its own inland aquaculture, the ability to oversee the industry to provide responsible regulation and subsidies where appropriate is far easier for the government to enact, as the harvest of these fishery products is not spread across an entire ocean. Data collection from these facilities will likely also prove to be far less costly than collection of data from the open ocean for this same reason. As aquaculture continues to improve in its implementation around the world, the US stands to benefit greatly by investing into an inland aquaculture industry, as fishery market demand continues to increase. By investment into this industry now, the US economy would not only be creating an insulated fishery market, safe from volatility caused through oil spills, but it would also likely lower the costs of regulation of these types of resources. Though a study into these costs is beyond the scope of this paper, certainly there exist a myriad of benefits beyond the insulation of the fisheries industry and the stability of prices due to this protection.

Limitations of this Study

The primary limitation of this study is the fact that the Sanchi oil spill is still quite recent, and thus the overall effect of the spill itself is impossible to calculate at this time. That being said, because the type of spill implied that the majority of the damage would be done in the short term, this paper is able to make that assumption. Further research would return to this oil spill outcome in particular to analyze the overall effect that the Sanchi spill had on the Chinese aquaculture market to determine the overall effect of the spill on Aquaculture in this context (if there is any). More research into other nations and their implementations of aquaculture would also support this research, as I have proven that certain methods of aquaculture simply do not work on the same scale as others. As many nations in both South America and throughout Asia have invested heavily into aquaculture themselves, a natural extension of my hypothesis would be to look into these economies as well to see how other aquaculture models would react to oil spill externalities.

Conclusion

Current US fishery policy is costly to the government as it attempts to mitigate the negative consequences of overfishing within our wild fishery stocks. This is an industry that coastal communities depend upon, as fishery products is a primary export of these communities, as serves as a primary source of employment for the people living in these areas. Unfortunately, this delicate balance of fishery sustainability in order to protect the long term prospects of the fishermen in these communities is often broken by market shocks due to oil spills and other forms of pollution. Therefore, in order to both expand the US fishery market and protect many who work in this industry from shocks due to oil spills, this paper has proven that inland aquaculture is a solution to the issue of oil shocks. As seen with the reaction of the Chinese fishery market after the Sanchi oil spill in 2018, inland aquaculture is unaffected by the damage caused to wild fisheries due to oil spill shocks, while in the US, the Deepwater Horizon Oil Spill in 2010 caused a great deal of damage to both the wild fisheries in the Gulf of Mexico as well as

US coastal aquaculture in this area. This insulation from oil shocks is the primary reason the US should invest into its own aquaculture industry, using China as a model to create a market that is unaffected by these frequent pollution events. Further benefits are expected in this industry transition, such as lowered regulation costs for the fishery industry in aggregate as more of the economy transitions into aquaculture and away from the more risky wild fishing. Though some externalities do still exist within the Aquaculture market, overall these externalities have largely been reduced due to technological advances from the Chinese. Investment in aquaculture will also reduce the rate of increasing prices for seafood, as is expected due to the fact that many fisheries are already operating at capacity or beyond it while demand is ever increasing. Investment into aquaculture is thus important to sustainably grow the US fishing industry as the world population continues to expand rapidly.

List of Tables:

Year	Chinese Aquaculture Production	US Gulf Fishery Extraction	Atlantic Fishery Extraction	Chinese Wild Fishery Production
1998	2.44E+07	715005.3	797921.2	3.99E+07
1999	2.66E+07	909210.7	704334.2	4.18E+07
2000	2.85E+07	814386.2	686350.1	4.33E+07
2001	2.99E+07	731726.1	755541.8	4.43E+07
2002	3.19E+07	784223.3	683667.6	4.63E+07
2003	3.36E+07	723893.4	711436.6	4.82E+07
2004	3.59E+07	669118.7	767266.6	5.07E+07
2005	3.76E+07	643591.3	693965	5.25E+07
2006	3.96E+07	617946.8	704945	5.46E+07
2007	4.12E+07	636989.5	653258.7	5.62E+07
2008	4.27E+07	580095.8	638461.2	5.78E+07
2009	4.53E+07	651213	661156.8	6.05E+07
2010	4.78E+07	486286.9	686693.6	6.35E+07

2011	5.02E+07	813094.5	696845.4	6.62E+07
2012	5.39E+07	675676	697289.9	7.04E+07
2013	5.71E+07	610652.2	599996	7.37E+07
2014	5.80E+07	564655.3	616083.1	7.61E+07
2015	6.10E+07	704567.6	620952.4	7.88E+07
2016	6.37E+07	787391.4	564403.1	8.25E+07
2017	6.52E+07	636025.2	584781.1	8.53E+07
2018	6.68E+07	674534.1	595623.1	7.35E+07

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