What impact has climate change had on Irish fisheries?

Rodney Beard[1]

Groupe Sup de Co La Rochelle[2]

La Rochelle, France

beardr@esc-larochelle.fr

Abstract: The potential impact of climate change on industry is frequently speculated about, but the actual historical impact of climate change on industry is rarely studied. Studies of the impact of climate change on fisheries have been largely simulation based or speculative and rarely use historical data. No studies of climate change test to see whether economic factors or physical and biological factors have a greater impact on the fishing industry. If policymakers are to make informed climate policy decisions environmental economists need to forecast the likely consequences of climate change on industry and be able to judge whether these consequences are large or small compared with changes due to other causes. In this paper, the impact of climate change on Irish fisheries is examined using a panel data set of 506 observations, consisting of 46 cross-sectional units and 11 longitudinal units. A comparison is made of the impact of economic factors and the impact of climate change on fisheries catch. It is concluded that climate change has had a considerable impact on the Irish fishing industry. An attempt is made to quantify the monetary impact of climate change on Irish fisheries and the loss to specific Irish fishing ports.

Keywords: Climate change, Environmental economics, Fisheries economics, Irish commercial fisheries

---

[1] I would like to acknowledge useful comments and discussions I have had concerning this research with Ralf Martin, Linda Nostbakken, Sharon O'Donnel, Stephen Hynes and Cathal O'Donoghue.

[2] La Rochelle Business School, La Rochelle, France.

1. Introduction

What has been the impact of climate change on fisheries? Current research has been largely speculative in nature or based on simulation studies, research approaches have involved dynamic mathematical models, biological studies and a few economics studies. Many studies, particularly older studies, consider climate change to be something that will happen in the future rather than an ongoing process, Drinkwater (2002) for example. Catch declines in the North atlantic have been attributed to a variety of causes including overfishing, and environmental factors such as climate change (Cook and Heath, 2005). A recent report by the Stockholm environment institute estimated that the cost of climate change to the world's oceans could be in the vicinity of $2 trillion (Noone, Sumaila and Diaz, 2012). Such forecasts are highly speculative in nature because they are based on future out of sample predictions involving a plethora of assumptions. Tol (2002) has attempted to quantify the both the market and non-market costs of climate change on a global scale, recognizing that there are considerable uncertainties in such analyses. In particular, he identifies three source of uncertainty about climate change: i) the magnitude of climate change and regional patterns are uncertain, ii) research into climate change needs to be improved, and iii) climate change will occur in a distant future. While the second of these is undoubtedly true, the first and third points are predicated on the assumption that climate change is something that will happen in the future. There are a number of problems with this perspective. Firstly, research into climate change has accumulated a considerable body of temperature data through measurement (for ocean temperatures see for example Rayner, et al. 2003 and 2006). This data is rarely exploited in economic analyses of climate change. Analyses of the impact of climate change in economics have been dominated by agricultural studies an in that literature cross-sectional analyses of regional differences in the impact of weather conditions have dominated the research agenda (Mendelsohn and Dinar, 2009).

Economic analyses have been less common. However, a number of papers have examined the impact of climate change on fisheries. So for example Arnason (2007) conducts an econometric analysis combined with a simulation study of the impact of climate change on fisheries in Greenland and Iceland and concludes that climate change would be beneficial to these fisheries. Ekerhovd (2008) using a descriptive analysis of Norwegian data, similar to the data used here, considered possible impacts of climate change on the Norwegian fishing fleet. His analysis stops short of a detailed econometric model of the impact of climate change on the fishing industry and the possible impacts considered are largely speculative or based on a reading of the scientific literature. Lorentzen and Hannesson (2005) consider the possible impact of climate change on the Norwegian cod fishing industry, they develop a series of econometric and bioeconomic models of catch in their paper, the econometrics being based on estimated demand relationships, with catch assumed to equal quota. They conclude that warming would lead to an increase in catch for the Norwegian cod fishery, a result that is in line with Arnason's findings. In other work Link and Tol (2009) develop a bioeconomic simulation model to assess likely impacts of a weakening of the thermohaline circulation, of which the gulf stream is a part, on Barents sea fisheries, particularly cod and capelin. Their results are mixed anositive impacts d vary by species and harvesting strategy, however they are not all negative with positive impacts on cod, a result that supports that of Lorentzen and Hannesson. Nevertheless this study considers future scenarios that may or may not eventuate, rather than what the impact has actually been.

Arnason's results provide support for the earlier biologically based research of Rose (2005) who show that warming of arctic waters has produced a northward shift of a number of species. For example Sundby and Nakken (2008) and Planque and Fox (1998) find that Irish sea cod respond with poor year classes in warm years and good year classes in cold years. What drives these responses? Temperature has a number of biological impacts on fish, including positive impacts such as shorter maturation and increased egg production as well as impacting prey abundance either positively or negatively. In terms of prey abundance, reduced abundance in temperate waters and increased abundance in colder waters have been observed. One biological mechanism for this appears to be migration of copepods northwards in response to warmer waters and a resultant shift northward of fish that eat these. If fish are migrating northward as some of the biological evidence and expertise suggests, then this raises the question as to what impact this is having on more southern fisheries, are we faced with a general northward migration of fish stocks or are some fishing areas losing out as a result of such migration. In order to investigate at least in part what the impact of climate change has been on fisheries in subarctic waters. In this paper we study the impact on Irish fisheries, Ireland has been strategically located for many years in a mid-way position between more southerly north Atlantic fisheries such as France, Spain and Portugal and the more northerly North Atlantic fisheries of Norway, Greenland and Iceland. Mac Laughlin (2010) has argued that fishing has been historically important to the Irish economy but that recently beginning in the nineteenth century fisheries and fishing communities have been neglected by both policy makers and academic analysts. Sweeney et al. (2008) in a report on the Impact of climate change on Ireland overlooked possible impacts on the fishing industry. Since then some research has been conducted on the science side. Cheung W. L. et al. (2012) review the state of the art of research on the impact of climate change on fisheries in the UK and Ireland and note that "A major difficulty in assessing the magnitude of these impacts is to directly attribute observed changes in fisheries to climate and ocean changes rather than other stressors such as intensive fishing pressure". This question is the starting point of this paper. In the analysis presented here an attempt is made to explicitly control for factors such as fishing pressure (fishing effort) and demand effects such as prices and untangle these from the impact of climate change, in the form of ocean warming, on landings of fish.

In this paper, a different approach is taken to that of most existing studies of the impact of climate change on fisheries. Firstly, historical temperature anomaly data is used in conjunction with historical landings data to estimate an econometric supply model, and the assumption that fishermen are price takers and that ocean temperatures have no impact on the demand for fish. A series of models are estimated to determine the most appropriate model for predictive purposes. Unlike the usual approach in the literature, future climate change is not considered, instead the analysis is confined to considering the costs of historical climate change during the sample period 1994-2004 to the Irish fishing industry, and in particular to identify the distribution of economic losses from warming of the ocean by port. All predictions are therefore within riod the sample pand not out of the sample period. Two scenarios are considered and compared, one the base case uses temperature anomaly data to establish the estimated value of landings at each port. Secondly, under the assumption of no temperature anomaly, i.e. no ocean warming, the value of landings is determined and the difference between these two scenarios calculated in order to estimate the economic loss to each port due to climate change. As far as I am aware the approach taken in this paper is novel. An advantage of the approach is that it is very much data driven and does not rely on assumptions about future scenarios that may or may not arise. Considering what the actual costs of climate change have been so far, will I believe help to drive the point home that the impact of climate change is not something that will only occur in a remote future but that it already has and is impacting communities in their daily lives.

This paper is organized as follows the next section examines the background of Irish fisheries and the Irish fishing industry, section 3 examines the available data, in particular landings data and seas surface temperature data that will be analysed in section 4, section 5 considers predicted impacts of climate change on the Irish fishing industry as a whole and in particular on Individual Irish fishing ports and section 6 concludes.

2. Backround on Irish Fisheries

The Irish fishing industry (if understood to be synonymous with seafood) contributes over 700 million euros annualy to the Irish national economy (Bord Iascaigh Mhara, 2011). It employs approximately 11000 people of which just under 50% are fishermen. Ireland is the ninth largest fishing nation in the EU27 measured by catch (EUROSTAT, 2009). Fishing in Ireland has a long tradition with the development of commercial fishing beginning in the medieval period and then slowly evolving until its current state (Mac Laughlin, 2010). The waters around Ireland are abundant with a variety of marine species (Marine Institute, 2009). Species considered in this study can be broadly grouped into demersal, pelagic and deepwater species. Demersal species are caught close to the bottom usually by trawling and those species landed at irish ports include: Cod, Saithe, Haddock, Whiting, Ling, Plaice and Sole. Pelagic species include Mackerel, Horse mackerel, Herring, Sprat, Sardines, Tuna, and Swordfish. Deepwater species are fished in depths of 400m or more and include: Argentines, Atlantic redfish, Black scabbardfish, Blue ling, Greater forkbeard, Orange roughey, roundnose grenadier and tusk. Sea surface temperature changes are perhaps most likely to impact pelagic and demersal fisheries. Pelagics because of their migratory nature and demersal because they tend to fish shallower coastal waters. EU regulations designate certain ports as landing ports for specific species. Details on this may be obtained from the sea fisheries protection authority (SFPA) (http://sfpa-ie.access.secure-ssl-servers.biz/index.php?q=news/the-sea-fisheries-protection-authority). Before landing fish at a port prior notification must be given to the fisheries monitoring centre of the Irish Navy at Haulbowline, this is referred to as “hailing”. Data employed in the present analysis are obtained from the Central statistical office landings survey, which draws on information from the SFPA and the fisheries monitoring centre.

3. Data

The data consist of a panel data set of 46 cross-sectional units and 11 longitudinal units, a total 506 observations. The data are drawn predominantly from the Irish central statistical office (CSO) Fishery landings survey. This is an annual survey of Irish registered fishing ports which collects information on the following variables: Species of fish and species class, landings by port/consumption category/month/average live weight per tonne, value by main species. In addition Northern hemisphere annual average seas surface temperature data were taken from the Hadley centre/Climatic research unit climate data repository at the University of East Anglia. A number of other variables were obtained from the Irish Sea Fisheries Protection Authority concerning designated landing ports for particular fish species these were broadly classified into demersal, pelagic and deepwater fish species and dummy variables constructed to represent whether a port was a designated port for landing this particular class of fish.

Table 1: Descriptive statistics of some key variables

	Landings	Value	Price	SST	Boats	Tonnes	Kw
Mean	4988.00	3138.00	1.53732	0.306273	1742.18	69141.0	213780

Median	912.500	1235.00	1.48829	0.329000	1689.00	64836.0	212680
Maximum	173022	39037.0	6.21739	0.479000	2105.00	86862.0	229093
Minimum	0.000000	0.000000	0.100206	0.104000	1436.00	59047.0	205956
St dev	17378.4	5516.99	0.972625	0.118978	210.925	10518.0	6862.50
CV	3.48405	1.75812	0.632675	0.388471	0.121069	0.152124	0.0321008
Skew	6.33863	3.77433	1.37914	-0.0673918	0.296907	0.666854	0.986092
Kurtosis	43.4422	16.7460	3.56991	-1.24287	-1.16279	-1.20906	0.0110204
N	478	478	450	11	506	506	506

The key variables that we are interested in are landings, price and SST. Examination of the descriptive statistics for landings, indicate that this variable is highly skewed to the right and that this issue will need to be addressed in the estimation procedure to follow. Value of landings and price are only moderately right skewed by comparison, temperatures moderately left skewed, which is to be expected for temperature anomaly data.

4. Econometric Analysis

In this section we discuss the econometric estimation of the Irish fisheries supply response and how it shifts in response to the warming of Northern hemisphere oceans. To do this we specify the following one-way fixed effects model:

$$y_{it} = \alpha + x_{it}'\beta + D_i'\gamma + \mu_i + \nu_{it}, i = 1, \dots, N, j = 1, \dots, T$$

Where

y_{it} are landings of fish at port *i* in period *t*

x_{it} is a 1xK vector of explanatory variables including price; sea surface temperature, fishing effort variable such as the number of boats, tonnage and energy consumption of the fleet (kw).

D_i is a 1xJ vector of dummy variables representing time independent policy factors such as whether or not a port is a designated landing port for a particular type of fish (demersal, pelagic or deepwater species). Initially one might consider a somewhat naïve empirical supply relationship between landings and the price at each port along with sea surface temperatures and a series of control variables representing different measures of fishing effort and some other factors. So for example one might be tempted to initially estimate supply using a pooled OLS estimator by regressing landings on price, SST, the number of boats the total tonnage and the energy consumption of the fleet. Additionally, one might consider whether or not designated port status has an influence on landings and whether or not different types of fishing licenses have an impact. Four types of fishing licenses are considered: commercial, drift, draft, other and rod fishing licenses. All control variables are aggregate but vary over time. Price however is imputed from value and landings data for each port. This suggests three different regression models the results of which are presented in the following table:

Table 2: Pooled OLS estimates of log landings

	Dependent variable is log of landings in each case			
	Model 1-1	Model 1- 2	Model 1-3	Model 1-4

Intercept	8.05842*** (2.50158)	22.5155*** (7.118)	7.66907*** (1.7425)	28.9942*** (10.2166)
Price	-0.859157*** (0.0660971)	-0.633377*** (0.0475912)	-0.625002*** (0.047486)	-0.869782*** (0.0662509)
SST	-1.03597 (0.705519)	1.34411 (1.17201)	-0.819544* (0.491512)	2.08191 (1.68299)
Boats	-0.00140648* (0.0007676)	-0.0069146** (0.00298146)	-0.00106308** (0.000534918)	-0.00963031** (0.0042792)
Tonnes	-1.18828e-05 (2.16963e-05)	-8.47124e-05* (4.5569e-05)	-1.336e-05 (1.51121e-05)	-0.000118287* (6.54252e-05)
Kilowatts	1.84097e-05 (1.76766e-05)	4.78035e-05* (2.76691e-05)	1.24538e-05 (1.23154e-05)	7.24317e-05* (3.97135e-05)
Deepwater (dummy)		0.662316*** (0.12967)	0.661851*** (0.129869)	
Demersal (dummy)		0.886725*** (0.107515)	0.890996*** (0.107657)	
Pelagic (dummy)		1.16137*** (0.124929)	1.16729*** (0.125088)	
Commercial		0.00146793* (0.000885219)		0.00186305 (0.00127148)
Drift		-0.011561** (0.00540887)		-0.0162768** (0.0077639)
Draft		0.00209471 (0.00232591)		0.00220587 (0.00334156)
Other		Collinearity		Collinearity
Rod		-6.94695e-05 (8.46415e-05)		-9.20162e-05 (0.000121591)
R-squared	0.279284	0.656935	0.652723	0.287045
F	34.41076	69.73439	103.6100	19.68331
Akaike criterion	1529.772	1209.725	1207.216	1532.899

Note: HAC[3] robust standard errors in parentheses.` ***' indicates significant at the 1% level , `**' significant at the 5% level and `*' significant at the 10% level.

The results clearly indicate that these models are not well identified because the price coefficient has the wrong sign. A supply response should respond positively to price increases. Analysis of the residual plot does not however suggest that price is correlated with an omitted variable and that instrumental variables estimation should be considered. Nor does estimating these models using fixed effects to adjust for cross-sectional heteroskedasticity solve the problem. The problem is not a matter of shifting the supply curve which could be solved via IV but one of rotating the curve. What is needed is a way to rotate the supply curve so that it is upward sloping. A rotation implies a multiplicative rather than an additive transformation so one possibility is to consider interaction effects. So following this logic the previous naïve models were re-estimated after including interaction effects with price and the effort variables and the license variables. The rationale being that price and effort and price and license purchases may somehow be related. Only after specifying a properly identified supply model will it be possible to conclude anything about the possible impact of ocean warming on fish supplies.

[3] For a discussion of the use of robust standard errors see for example Arellano (1987) and Stock and Watson (2008).

The results indicate that this conjecture is in fact correct including interaction terms between price and the effort variables do seem to play an important role however simply including interaction terms is not by itself sufficient. Some interactions may not for example be relevant.

Table 3: Pooled OLS estimates with interaction terms

	Dependent variable is log of landings in each case			
	Model 2-1	Model 2-2	Model 2-3	Model 2-4
Intercept	7.98116* (4.6444)	5.81039** (2.5767)	8.83419*** (0.224236)	7.72022*** (0.163651)
Price	-0.265708 (2.40907)	0.806916 (0.531076)	0.610336* (0.337276)	0.413664* (0.234199)
SST	-0.972093 (0.699947)	-0.99974 (0.698575)	-1.18942* (0.60629)	-1.14964*** (0.420759)
Boats	0.000820133 (0.00141241)	-0.00030897 (0.000835489)		
Tonnes	0.00141241 (3.6592e-05)	-2.13266e-05 (2.16866e-05)		
Kilowatts	-6.56949e-06 (3.06359e-05)	2.33575e-05 (1.75701e-05)		
Deepwater (dummy)				0.645844*** (0.127971)
Demersal (dummy)				0.894177*** (0.105985)
Pelagic (dummy)				1.1593*** (0.123173)
Price x Boats	-0.00167808** (0.000781037)	-0.00100472*** (0.000317824)	-0.000884398*** (0.000205557)	-0.000629548*** (0.000143131)
Price x Tonnes	-1.84726e-05 (1.7471e-05)			
Price x Kilowatts	1.64797e-05 (1.38445e-05)			
R-squared	0.297598	0.295184	0.292105	0.661466
F	23.35572	30.92207	61.34551	144.2636
Akaike criterion	1524.189	1521.733	1517.695	1191.743

Note: HAC robust standard errors in parentheses.` ***' indicates significant at the 1% level , `**' significant at the 5% level and `*' significant at the 10% level.

Model 2-1 with interaction terms does not solve the problem either but it does identify that the interaction between price and boats might be important. Possibly the other interaction terms are not relevant, they are not significant at least, so dropping these out we get model 2-2, this is just model 1-1 with an interaction term for prices and boats added. This model captures the supply response appropriately. However the result is not significant. Nevertheless this is the first model that has produced a price coefficient with the correct sign. By comparing the different models in table 3 it should be apparent that the positive sign for the price coefficient is relatively robust to a variety of specifications as long as the model contains the boat x price interaction term.

Estimation based on pooled OLS is problematic as it ignores the panel structure of the data and cross sectional heterogeneity. Essentially it ignores the μ_i term in equation (1). Alternatively one can estimate (1) using a fixed effects panel data estimator. This allows one to account for cross-sectional heterogeneity in a way that pooled OLS does not. For purposes of comparison each of the models in table 3 except for model 4 which falls foul of the dummy variable trap is re-run using fixed effects

Table 4: Initial fixed effect results with interaction terms

	Dependent variable is log of landings in each case		
	Model 1	Model 2	Model 3
Intercept	7.08214*** (1.69301)	7.49057*** (1.37976)	7.82651*** (0.143842)
Price	0.940891 (1.0806)	0.473878 (0.403611)	0.0339317 (0.170926)
SST	-0.614757** (0.000731436)	-0.650699** (0.312165)	-1.04657*** (0.291272)
Boats	0.00118849 (0.000731436)	6.60897e-05 (0.000555872)	
Tonnes	1.37536e-05 (1.35083e-05)	-1.5096e-05* (8.39063e-06)	
Kilowatts	-1.12839e-05 (9.48463e-06)	5.45469e-06 (5.93546e-06)	
Price x Boats	-0.0011425*** (0.000417385)	-0.000451681 (0.000280314)	-0.000184591 (0.000115275)
Price x Tonnes	-1.71494e-05*** (5.46512e-06)		
Price x Kilowatts	9.05784e-06* (4.99573e-06)		
R-squared	0.859563	0.858067	0.855912
F	45.73141	47.17937	49.62531
Akaike criterion	889.8036	890.5698	891.3532

Note: HAC robust standard errors in parentheses.` ***' indicates significant at the 1% level , `**' significant at the 5% level and `*' significant at the 10% level.

One problem with these results is the lack of significance of the price coefficient which suggests that the price effect is not particularly robust to this specification. Once again, this indicates that the model is not properly identified. So we try the same idea as before and again consider adding an interaction term with price, the natural candidate is the interaction between price and vessel size measured in tonnes. A second issue is that the institutional dummies for designated ports can no longer be included due to the dummy variable trap. These are therefore dropped in what follows.

Table 5: Fixed effect results with interaction terms

	Dependent variable is log of landings in each case			
	Model 3-1	Model 3-2	Model 3-3	Model 3-4
Intercept	7.75096*** (0.149922)	6.54658*** (0.565432)	8.38101*** (0.646848)	5.866*** (1.54451)
Price	0.825942* (0.486612)	1.53886** (0.582014)	0.609881 (0.632946)	1.8635** (0.901542)
SST	-0.911326*** (0.300784)	-0.631538** (0.325047)	-0.702119** (0.331533)	-0.650686** (0.308)
Boats		0.00065369 (0.000296016)		0.00085261 (0.000624294)
Tonnes			-9.71426e-06 (7.82488e-06)	4.84251e-06 (9.71967e-06)
Price x Boats	-0.000404418** (0.00017095)	-0.000761901** (0.000234839)	-0.000430117** (0.000183848)	-0.000857873** (0.000367361)
Price x Tonnes	-5.58606e-06* (3.21452e-06)	-7.23007e-06* (3.28454e-06)	-2.13185e-06 (5.2109e-06)	-9.45225e-06* (5.20795e-06)

R-squared	0.856991	0.858718	0.857909	0.858786
F	48.91903	48.50280	48.18111	47.45922
Akaike criterion	889.9687	886.5022	889.0724	888.2852

Note: HAC robust standard errors in parentheses.` ***' indicates significant at the 1% level , `**' significant at the 5% level and `*' significant at the 10% level.

From these results one sees that model 3-3 can be eliminated because the price coefficient is not significant. Model 3-4 is a possible candidate but the main control effects are not significant based on the model selection criteria the most plausible model appears to be model 3-2.

Why does this estimation procedure work? Consider the following generic model with interaction terms:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \varepsilon$$

This may be rewritten $y = \beta_0 + (\beta_1 + \beta_3 x_2)x_1 + \beta_2 x_2 + \varepsilon$, the term in brackets may be interpreted as the slope of x_1, if this is estimated to be negative then a number of explanations are possible. Firstly, $\beta_1 < 0$ and may dominate $\beta_3 x_2 > 0$, or $\beta_1 > 0$ with $\beta_3 x_2 < 0$ and large or both terms may be negative. The second term will be negative if the sign of β_3 and x_2 is negative and positive otherwise. The case of interest here is whether or not the coefficient of x_1 is negative in the latter case and positive in the former. How can we explain the negative interaction between boats and prices? One explanation is that boats enter in response to higher prices but price effects have less impact on landings as the fleet grows in size, this is counter to what one would expect in an unfettered market where as the number of firms increases, the market supply curve becomes flatter (price on vertical axis), however, the fishing industry is regulated through a quota system as landings approach the quota this will lead to the supply curve becoming steeper (more inelastic), so the sign on this interaction terms can be interpreted as resulting from a combination of an aggregation effect with a quota restricting the ability of the market ro respond to price signals.

Why not IV? Instrumental variables along the lines of Hausman and Taylor (1981) would be appropriate if price were correlated with the fixed effects, this is plausible if prices were time invariant however as they vary considerably over time as well as by port such correlation is not likely to be strong, this explains why panel IV fails to estimate the supply relationship in this case. Price variation is not purely correlated with port specific factors. IV estimation will not significantly correct the problem of the price coefficient having the incorrect sign (see last model in Table 6).

Perhaps the relationship between landings and sea surface temperatures is simply reflecting a downward trend in landings over time and an upward trend in temperatures over time. The correlation between log landings and time is -0.03792527 and indicates no relationship between time and landings, SST however is time dependent with a correlation of 0.72631472. This suggests that it might be worth considering using time and boats as instruments in an instrumental variable model. To do this a slightly different benchmark model will be used consisting of Price and SST as exogenous variables and the log of landings as the endogenous variable. The models presented in the following table are chosen to indicate the progression in reasoning.

Table 6: Comparison of Instrumental variables estimates

	Dependent variable is log of landings in each case			
	Model Pooled OLS	Model Pooled IV	Model Panel IV	Model Panel IV with interaction terms
Intercept	8.28119*** (0.346776)	7.107*** (0.505161)	7.54397*** (0.247395)	7.59934*** (0.620370)
Price	-0.814515*** (0.162251)	0.268053 (0.337303)	-0.0113763 (0.240330)	0.483649 (0.584482)
SST	0.14236 (0.442367)	-1.46908** (0.57124)	-1.49339*** (0.555274)	-0.932147** (0.379489)
Time		Instrument	Instrument	Instrument
Boats		Instrument	Instrument	Instrument
Tonnes				Instrument
Kw				Instrument
Price x Boats				-0.000184778 (0.000294366)
Price x Tonnes				-4.62632e-06 (4.15688e-06)
R-squared	0.262724	0.175104	0.045613	0.084063
F	79.64280	3.325332	31.9077	32.4512
Akaike criterion	1533.994	6785.962		

Note: HAC robust standard errors in parentheses.` ***' indicates significant at the 1% level , `**' significant at the 5% level and `*' significant at the 10% level.

The pooled OLS model once again results in the wrong sign for price, rerunning the same model using instrumental variables, with Boats and Time as instruments corrects the problem, however dropping time as an instrument would not correct the problem. However, a problem with this result is that price is not significant. Secondly, cross-sectional heterogeneity is not accounted for. Re-estimating the model using panel instrumental variables, the results show that the sign of the price coefficient is neither significant nor robust. However, if one now incorporates interaction effects into the model, then the results are quite similar to non-instrumental variable model (model 3-1) except that neither price nor the interaction terms are significant. The model also indicates that Price, SST and the two interaction terms are endogenous. However only SST and the intercept are significant and the results appear otherwise unconvincing due to poor fit to the data when compared with the non-instrumental variable estimates.

What about the possibility of idiosyncratic temperature shocks in particular years? Because the model uses seas surface temperature and sea surface temperatures tend to vary less than air temperatures this possibility seems unlikely. Because SST is a common regressor it may be that idiosyncratic shocks have an impact on landings. Landings at particular port may not be independent but linked via the common temperature shock and it could be that this is what is contributing to the contemporaneous correlation between SST and landings. In order to eliminate this possibility the model was rerun using both fixed effects and time dummies and then re-run with pooled OLS and time dummies. In addition clustered standard errors were used by clustering on any significant time dummies (years 4 and 6 were significant). Eliminating all but the significant time dummies and re-running the regression clustering on either of these dummies it is found they are no longer significant. The sign of the coefficient on SST remained the same throughout this exercise. The result is that the impact of SST on landings is robust to a variety of model specifications.

What impact are changes in the exogenous variables likely to have on landings can be determined from the following tables of partial effects.

Table 7: Partial effects

	Dependent variable is log of landings in each case			
	Model 3-1	Model 3-2	Model 3-3	Model 3-4
Price	0.825942-0.000404418xBoats--5.58606e-06xTonnes	1.53886-0.000761901xBoats-7.23007e-06xTonnes	0.609881-0.000430117xBoats-2.13185e-06xTonnes	1.8635-0.000857873xBoats-9.45225e-06xTonnes
SST	-0.911326	-0.631538	-0.702119	-0.650686
Boats	-0.000404418xPrice	0.00065369-0.000761901xPrice	-0.000430117xPrice	0.00085261-0.000857873xPrice
Tonnes	-5.58606e-06xPrice	-7.23007e-06xPrice	-9.71426e-06 --2.13185e-06xPrice	4.84251e-06 --9.45225e-06xPrice

From the partial effects table it can be seen that while price increases generally lead to increased landings (the supply curve is upward sloping), new entry in the form of more and larger boats can lead to a fall in landings due to a rotation of the supply curve. Increases in sea surface temperatures will have a negative impact on landings.

Because the panel data set employed in this study is unbalanced there is a question of whether or not missing observations are random or not, attrition of ports is presumably due to a fall in landings to such an extent that the ports fishing operations are closed. Therefore attrition may not in fact be random and this could lead to significant biases in the results. Cursory observation of the dataset, suggests that attrition is probably not a serious issue nevertheless this is something that should be tested for. The previous fixed effect panel data models were re-estimated using the approach of Nijman and Verbeek (1992), i.e. a lagged dummy variable for a cross-sectional unit being included in the sample was also included in the regression model. The results are presented in the following table.

Table 8: Fixed effects estimates with interaction terms and controlling for attrition

	Dependent variable is log of landings in each case			
	Model 3-1	Model 3-2	Model 3-3	Model 3-4
Intercept	6.80003*** (0.847755)	6.80003*** (0.847755)	9.05928*** (0.638915)	4.67619** (2.19443)
Price	1.7859** (0.723778)	1.7859** (0.723778)	0.522437 (0.705096)	2.80487** (1.11061)
SST	-0.648873** (0.27768)	-0.648873** (0.27768)	-0.737939** (0.313021)	-0.714974** (0.301384)
Boats		0.000915718* (0.000527753)		0.00159095* (0.000910725)
Tonnes			-9.97153e-06 (7.60286e-06)	1.42214e-05 (1.22643e-05)
Price x Boats	-0.000891012** (0.000346413)	-0.000891012** (0.000346413)	-0.000375125* (0.000215967)	-0.0012183** (0.000478882)
Price x Tonnes	-7.44187e-06* (4.02825e-06)	-7.44187e-06* (4.02825e-06)	-1.69834e-06 (5.46964e-06)	-1.39023e-05** (5.84043e-06)
S_i,t-1 (attrition	-0.714376**	-0.714376**	-0.703093**	-0.729673**

dummy)	(0.298867)	(0.298867)	(0.295623)	(0.304993)
R-squared	0.866176	0.866176	0.864565	0.866712
F	45.18071	45.18071	44.56020	44.39236
Akaike criterion	793.1813	793.1813	798.0640	793.5452

Note: HAC robust standard errors in parentheses.` ***' indicates significant at the 1% level , `**' significant at the 5% level and `*' significant at the 10% level.

Port characteristics may not however be fixed. A number of cross-sectionally related factors may come into play in decisions to land catch at a particular port, these include, whether proximity of the port to a boats location at the time the decision to head to port is made[4]. Such random factors may still be present in the data even though annual data is being employed. To account for this a random effects model was considered. The results presented below indicate that the GLS estimates are not consistent based on the Hausman test.

Table 9: Random effects results controlling for attrition

	Dependent variable is log of landings in each case			
	Model 3-1	Model 3-2	Model 3-3	Model 3-4
Intercept	7.77448*** (0.223623)	6.62662*** (0.77564)	8.43441*** (0.452372)	4.61278** (1.98039)
Price	0.774214 (0.493487)	1.89611** (0.739284)	0.546911 (0.515445)	2.86157** (1.14499)
SST	-0.95578*** (0.304891)	-0.676811** (0.332572)	-0.744971** (0.335059)	-0.738908** (0.33663)
Boats		0.000957169*** (0.000358455)		0.00159778** (0.000681718)
Tonnes			-9.96877e-06 (6.17537e-06)	1.34885e-05 (1.22045e-05)
Price x Boats	-0.00045219*** (0.000172972)	-0.00102598*** (0.000322318)	-0.000483551*** (0.000174841)	-0.00133463*** (0.000427798)
Price x Tonnes	-4.80249e-06 (3.25552e-06)	-1.33176e-05* (3.70381e-06)	-1.1743e-06 (3.93908e-06)	-1.33176e-05** (6.66235e-06)
S_i,t-1 (attrition dummy)		-0.573554 (0.400028)		-0.591444 (0.399406)
Akaike criterion	1588.766	1450.812	1586.860	1453.737
Breusch-Pagan test	1107.5***	906.473***	1108.68***	906.318***
Hausman test chi-squared	17.6164***	29.0599***	27.2404***	28.6933***

Note: HAC robust standard errors in parentheses.` ***' indicates significant at the 1% level , `**' significant at the 5% level and `*' significant at the 10% level.

[4] " Landings from Castletownbere's fleet of eight pelagic vessels are handled by fish agents based in the town. Catches may be landed into the Castletownbere Co-op, but more often are landed either direct to processors in Killybegs who take 37% of the catch by volume from Castletownbere-registered vessels, or elsewhere in Ireland or overseas. Those interviewed stated that, where possible, they land their pelagic catches locally in Castletownbere although it was sometimes necessary to land elsewhere due to weather and other factors " (BIM, 2012, p. ix).

In the next section within sample forecasts are considered in order to evaluate the implications of the model for a world with and without warming. Out of sample forecasts are not considered at this stage.

5. Estimating the Impact of climate change

In order to construct forecasts two approaches are employed. For within sample predictions actual values of the exogenous variables are employed. However for sea surface temperatures two situations are considered the actual observed sea surface temperature anomaly figures and secondly the counterfactual case of no seas surface warming in which case sea surface temperature anomaly (SST) is set to zero. In order to estimate the fixed effects for prediction purposes, following Baltagi (2008) a model of the following form was estimated:

$$y = \alpha\iota_{NT} + X\beta + Z_{\mu}\mu + \nu$$

Where y is a NTx1 vector of log landings, ι_{NT} is a vector of ones of dimension NT, X is of dimension NTxK and Z_{μ} is a matrix of unit specific dummies with dimension NTxN.

Based on the preceeding analysis of various model specifications, model 3-1 was chosen for the simulation, exogenous variables were therefore price, SST, the interaction between price and bots and the interaction between price and tonnes. The estimation results are report in the appendix.

Baltagi notes that there are two ways to estimate this, firstly one may demean the dependent and independt variables by pre-multiplying by a projection matrix and then using OLS, secondly one may estimate the equation by OLS after dropping the the intercept $\alpha\iota_{NT}$ from the model. This is done to avoid the dummy variable trap. It is worth noting that using the Nijman and Verbeek (1992) method to control for attrition in unbalanced panels leads to the same issue and that for forecasting purposes with fixed effects attrition dummies are dropped as well. The latter approach was used, to extract the unit specific coefficients for predicting landings in the base case (historically observed levels of sea surface warming) and the counterfactual case of zero temperature anomaly.

The following tables consider for each port the difference in landings between actual measured landings and the predicted landings under the counterfactual case of no sea surface temperature warming ceteris paribus. The table reports the mean difference in landings between the actual and counterfactual, the variance, the minimum difference and the maximum difference and the total loss in landings due to warming.

Table 10: Estimated reduction in landings 1994-2004 due to ocean warming by fishing port in tonnes.

Port	mean	st dev	Min	Max	total
Achill	-125.5554731	46.54199316	-216.4120849	-57.49596358	-1381.110204
Aran Islands	-27.06438597	11.39061592	-47.88884537	-10.99219448	-297.7082457
Arklow	-247.0072119	78.01172194	-368.5247023	-104.2574802	-2717.079331
Ballycotton	-149.6321062	58.41441186	-241.9745035	-63.77597756	-1645.953168
Ballyglass	-49.06703464	20.72566666	-74.9804153	-20.80882371	-245.3351732
Baltimore	-1068.461017	135.3116962	-569.251517	-163.7156002	-4188.913547
Bantry	-21.07015527	6.532282917	-30.54113607	312.5629292	-147.4910869

Bunbeg	-53.2632608	15.1770607	-65.3507825	-36.2303219	-159.789782
Burtonport	-184.351412	52.7168635	-256.99341	-97.3441251	-2027.86553
Carlingford	-90.8731412	36.3227855	-132.924853	-39.5520612	-454.365706
Carna	-41.4568418	16.1275623	-68.3518744	-17.0991005	-456.02526
Carrigaholt	-61.2670164	22.572313	-97.4228409	-26.8653893	-673.937181
Castlegregory	-51.2978718	24.0259994	-86.4751596	-10.560597	-564.276589
Castletownbere	-2170.86613	673.700939	-3150.02067	-959.466781	-23879.5274
Cleggan/Clifden	-62.3966653	29.9238213	-101.628385	-25.2816128	-374.379992
Clogherhead	-173.595545	62.9636404	-278.165165	-75.957575	-1909.551
Cobh	-1752.63698	565.740682	-2692.34145	-726.848017	-19279.0067
Courtown	-96.9473379	32.6190578	-150.343401	-38.4398747	-1066.42072
Crosshaven	-118.256422	45.990434	-174.823787	-44.601414	-1300.82064
Dingle	-1307.36731	467.814013	-1995.03937	-530.850332	-14381.0404
Downings	-299.525898	101.930266	-444.067115	-104.454183	-3294.78487
Dun Laoghaire	-104.364801	34.8179932	-159.98395	-40.7065757	-1148.01281
Duncannon/St.Helens	-170.366229	75.0507827	-306.005869	-66.5115012	-1874.02852
Dunmore East	616.466216	5788.16578	-3694.41062	-991.516025	-25636.9265
Fenit	-323.646718	122.049005	-567.988955	-148.422756	-3560.1139
Foynes	-39.5873424	20.0911386	-72.2721395	-18.2327119	-237.524054
Galway	-137.012304	79.5198896	-266.622877	-38.926508	-822.073824
Greencastle	-768.43447	248.168975	-1085.68349	-292.095317	-8452.77917
Helvick	-116.520344	41.6820964	-188.391333	-46.0877563	-1281.72378
Howth	-1042.09603	357.44319	-1564.04376	-451.840957	-11463.0564
Killybegs	-22176.0114	7116.18815	-34025.617	-9168.23914	-243936.125
Kilmore Quay	-187.510265	67.3302452	-284.636095	-68.7357353	-2062.61292
Kincasslagh	-280.327916	96.4681081	-434.361174	-119.054931	-2522.95124
Kinsale	-299.623543	105.064265	-429.924152	-114.989412	-3295.85897
Lettermore/Lettermullen	-30.7692992	15.5918335	-49.1838513	-14.2851399	-184.615795
Malin Head	-217.067553	73.6549897	-324.691488	-86.1317787	-2387.74308
Moville	-96.2173326	33.1466034	-152.105132	-44.2493251	-1058.39066
Portmagee	-114.423062	35.9793677	-171.542703	-71.1021225	-915.384494
Rathmullan	-2687.85608	861.008069	-4161.62898	-1134.96455	-29566.4168
Rossaveal	-1679.63891	900.456709	-2585.5822	-707.300628	-18476.028
Schull	-206.518625	69.6146544	-313.366747	-82.3073566	-2271.70488
Skerries	-201.226395	68.5538004	-312.953112	-89.2574749	-2213.49035
Union Hall	-497.886851	180.860093	-807.68584	-216.610322	-5476.75536
Valentia	-154.992435	56.8974751	-229.8963	-57.6354694	-1704.91679
Wexford	-94.5505293	31.8867654	-135.392341	-36.5240056	-1040.05582
Wicklow	-900.927952	243.169248	-1229.93614	-581.270388	-6306.49566
Total					-458341.1674

The second table (table 10) reports the mean difference in revenue assuming constant prices (price taking firms and ceteris paribus) for each port between the actual and counterfactual situations, the variance, the minimum difference and the maximum difference.

Table 11: Impact of climate change on Irish fishing ports 1994-2004 in thousands of 2004 euros

	Mean loss in revenue	Standard deviation of revenue loss	Min revenue loss	Max revenue Loss (+ gain, - loss)	Total lost revenue 1994-2004 in thousands of 2004 euros	Total revenue Loss as percent of total revenue In the years 1994-2004
Achill	-207.3902599	166.9464114	-504.2954668	-27.38091446	-2281.292859	-32.76778022
Aran Islands	-126.7794123	87.95810247	-282.3816573	-21.1583089	-1394.573536	-30.38948651
Arklow	-201.568938	122.842791	-420.993278	-33.8822202	-2217.25832	-25.7670926
Ballycotton	-386.379329	266.474	-920.614076	-61.8241662	-4250.17262	-29.9962779
Ballyglass	-68.9154768	46.5978591	-145.87099	-22.8364663	-344.577384	-16.7840908
Baltimore	-1061.44519	386.434512	-1348.05175	-97.7540316	-6580.18342	-28.3701967
Bantry	-78.2659705	36.6695802	-127.873476	-28.2306839	-547.861793	-20.3666094
Bunbeg	-71.935637	46.3392871	-124.845862	-38.5732387	-215.806911	-20.0006405
Burtonport	-512.255044	361.174305	-1117.0098	-52.9069743	-5634.80548	-31.6597679
Carlingford	-30.3222198	32.3123652	-87.0053586	-7.55256846	-151.611099	-9.49944231
Carna	-208.112298	144.133344	-440.119311	-32.7104933	-2289.23527	-30.1294456
Carrigaholt	-188.5229477	138.7608524	-466.3345651	-30.48922705	-2073.752425	-29.7610853
Castlegregory	-198.6036682	136.1056172	-420.5180383	-34.2234817	-2184.64035	-29.7594381
Castletownbere	-3950.162399	2652.187585	-7848.693077	-550.9112751	-43451.78639	-30.7586247
Cleggan/ Clifden	-96.44005366	60.61123929	-211.5105814	-35.6058501	-578.640322	-15.5048318
Clogherhead	-556.3582286	377.1440667	-1130.747255	-87.3303305	-6119.940514	-29.1814825
Cobh	-779.8745343	487.8052636	-1430.520704	-138.103248	-8578.619877	-29.1195515
Courtown	-79.19730409	54.07413723	-173.0906099	-16.61216654	-871.170345	-28.3215327
Crosshaven	-262.0640842	161.0649241	-565.261075	-51.07581285	-2882.704926	-26.1090927
Dingle	-2537.775757	1567.035462	-5355.679497	-463.6142813	-27915.53333	-27.9054874
Downings	-662.7752871	472.1196106	-1537.630452	-128.4527468	-7290.528158	-27.1194739
Dun Laoghaire	-105.3524471	67.31410037	-219.4833458	-22.25427987	-1158.876918	-28.0192678
Duncannon/St.Helens	-399.0302848	283.7490279	-934.791456	-74.88942628	-4389.333132	-30.0002265
Dunmore East	-3175.29078	2370.04764	-7256.81742	-490.843012	-34928.1986	-30.7867632
Fenit	-580.305146	433.216125	-1385.74021	-85.1446682	-6383.3566	-21.104796
Foynes	-79.8118333	47.5832182	-167.710861	-27.7049329	-478.871	-13.9004644

Galway	-106.333598	29.5433437	-138.015177	-62.2824128	-638.001589	-13.0177839
Greencastle	-1565.38932	958.065983	-2866.72842	-297.214942	-17219.2825	-29.5229876
Helvick	-303.480459	219.196414	-711.614007	-50.3469007	-3338.28504	-30.1234889
Howth	-2834.90996	1984.62442	-5882.56095	-433.599834	-31184.0096	-30.0340074
Killybegs	-9616.54241	6546.00556	-20506.9791	-1754.90696	-105781.967	-30.4643485
Kilmore Quay	-540.629587	365.449161	-1154.17438	-96.2605757	-5946.92546	-16.125069
Kincasslagh	-75.0875557	54.418612	-180.698963	-26.6827616	-450.525334	-13.0776585
Kinsale	-685.132155	428.83916	-1481.48718	-128.032117	-7536.45371	-29.3624253
Lettermore/Lettermullen	-71.6867755	46.010078	-158.697845	-25.0591174	-430.120653	-15.7611086
Malin Head	-363.42077	220.883694	-716.595883	-67.8545056	-3997.62847	-28.1265635
Moville	-122.698114	93.240277	-269.225171	-11.7599161	-1349.67926	-28.4143002
Portmagee	-456.197939	217.431475	-732.374899	-151.472018	-3649.58351	-36.7383079
Rathmullan	-1005.89408	706.67869	-2373.88192	-133.130807	-11064.8348	-27.5683547
Rossaveal	-2671.66715	1568.71424	-5900.8676	-427.08525	-29388.3387	-29.1470015
Schull	-535.5173484	338.9691972	-1019.493046	-92.94520137	-5890.690832	-29.7044568
Skerries	-639.7777036	422.5073487	-1189.837422	-100.9850162	-7037.554739	-30.9098504
Union Hall	-1190.851397	790.8344326	-2451.474409	-183.5473345	-13099.36537	-30.0892738
Valentia	-496.4940007	315.2192394	-987.409726	-88.38883459	-5461.434008	-28.6659354
Wexford	-86.0157087	55.27603363	-174.3621248	-20.28706004	-946.1727957	-17.8052841
Wicklow	-931.8874205	465.0044075	-1569.512817	-241.6174514	-6523.211943	-37.05738762
Total					-436127.3964	

This produces an estimate of the total loss to Irish fisheries of approximately 436 million euros during the period 1994-2004. I have not used discounted values to calculate the estimate, this would be unusual in any case as the data are historical, however all estimates are in 2004 euros. To judge this figure more accurately consider that Irelands GDP in 2004 was 147.567 billion euros. So the loss in eleven years in terms of climate change is only about 0.29% of Irelands GDP in 2004. However, as we shall see although the impact is small at the national level it can be quite substantial at the local level.

The losses are for the most part considerable with climate change accounting for up to around 30% revenue losses for many ports over the sample period. Which ports have been most heavily impacted can be seen in the following table with the worst affected ports listed from top to bottom. The worst impact of climate change has been on Wicklow this port lost approximately 37% (40%) of its actual (counterfactual) revenue in the period 1994-2004 due to climate change. The least impacted port has been that of Galway.

In terms of loss compared with the counterfactual ports can be ranked from those suffering the most damage to those suffering the least as follows:

Table 12: Rank ordering of ports by percentage revenue lost

Rank	Port	% change in revenue from counterfactual
1	Wicklow	-40.69272304
2	Portmagee	-36.67449513
3	Bantry	-33.777793
4	Moville	-33.29792883
5	Fenit	-32.80437168
6	Achill	-32.57707588
7	Burtonport	-32.39876129
8	Aran Islands	-31.41672685
9	Helvick	-31.40522437
10	Dunmore East	-31.38607148
11	Carna	-31.30293791
12	Howth	-31.29373167
13	Clogherhead	-31.22951581
14	Skerries	-31.16140661
15	Castletownbere	-31.00430994
16	Carrigaholt	-30.8893951
17	Castlegregory	-30.87284555
18	Union Hall	-30.82423635
19	Rathmullan	-30.70591493
20	Ballycotton	-30.62927367
21	Downings	-30.56245877
22	Killybegs	-30.5007673
23	Kilmore Quay	-30.48578687
24	Rossaveal	-30.37857802
25	Schull	-30.36592381
26	Valentia	-30.12835912
27	Cobh	-30.05141572
28	Courtown	-29.77619768
29	Greencastle	-29.76265189
30	Dun Laoghaire	-29.74508598
31	Kinsale	-29.64957889
32	Crosshaven	-29.34438545
33	Arklow	-29.31240854
34	Malin Head	-29.29955649
35	Duncannon/St.Helens	-29.11869054
36	Dingle	-29.08157479
37	Baltimore	-28.79389382
38	Wexford	-28.24628323
39	Bunbeg	-20.23807779
40	Carlingford	-19.9456652
41	Ballyglass	-17.20571098
42	Lettermore/Lettermullen	-15.71796686
43	Kincasslagh	-15.66304798
44	Cleggan/Clifden	-15.63034779
45	Foynes	-15.57798139
46	Galway	-13.03553762

What is driving the differences between ports is not immediately apparent. For example ports such as Portmagee and Valentia in Kerry are located only a few kilometres from each other yet Portmagee seems to have suffered considerably more from climate change. Local conditions likely play a role, these are small ports and boats are not likely to be fishing far from port (I can confirm this through direct observation). Aggregate north Atlantic sea surface temperature data should therefore be considered a proxy for local conditions. Local variation can amplify the impact of global changes quite considerably.

It is worthwhile to consider two ports in further detail, namely Castletownbere and Killybegs, the reason for this is that detailed socioeconomic case studies of the fishing industry have been conducted for these ports (BIM, 2012, and 2010). In the case of Castletownbere approximately, 54% of the local economy is directly dependent on the fishing sector. Local multipliers for Castletownbere suggest that for every million euros of landings an additional 2.12 million euros with a multiplier of 0.77 for landings by foreign vessels (BIM, 2012, p.14). As the balance of landings between domestic and foreign vessels is not available for the whole 1994-2012 period, one can consider a multiplier range of 0.77 to 2.12, employing these figures and combining this with loss in revenue due to climate change means that the actual impact of climate change on the towns fish processing industry is not 4..35 million euros (see table 10) but would lie within a range of 3.3 million to 9.2 million euros for the period 1994-2004. This indicates that in fact the damage due to climate change may be considerably larger than the figures presented in table 10 and table 11. Since 2004 landings in Castletownbere have not declined and the local industry has adapted well to changes in quotas, prices have mostly been increasing so that the value of landings has for the most part been maintained. However the analysis presented in this paper is concerned with opportunity costs. The local industry in Castletownbere has not grown, for example output from the processing sector has been relatively stagnant with the average daily output of the processing sector only increasing by 2% since 2003 (BIM, 2012, p.ix). While the worst effects of climate change are mitigated by adaptation, what we observe as a result gives little indication of the opportunity costs.

Killybegs, Donegal is the largest and most successful fishing port in Ireland. Approximately 82% of the local economy is dependent on the fishing sector. The local multiplier for fishing value to the processing and ancillary sectors is estimated to be 1.77 the loss in revenue due to climate change to the Killbegs fishing industry is about 10.6 milion euros, accounting for the multiplier effect on the local processing an ancillary sectors the opportunity cost of climate change to Killybegs has been about 18.7 million euros over the 1994-2004 period. Killybegs has been able to grow the value of its landings in the period since that considered in the analysis in this paper through a combination of increased prices, comparative advantage in attracting landings from vessels from other ports and expansion of pelagic fishing.

6. Conclusions

In this paper, an econometric model of the impact of sea surface temperature increases in the North Atlantic on Irish commercial fisheries has been presented. It was found that controlling for other factors such as fishing effort (e.g. boats) and prices at Irish ports, increases in Atlantic sea surface temperatures, indicative of warming ocean temperatures have had a negative impact on fish landings at Irish ports. Based on these results a simulation was conducted in which monetary damages due to climate change were estimated for 46 Irish ports, while not all ports were negatively impacted by climate change to the same degree the vast majority of Irish ports appear to have suffered revenue losses in the vicinity of 30% of the revenue that they would have earned in the absence of global warming, it is estimated that the total cost to the Irish fishing industry of climate change in the period 1994-2004, has been in the vicinity of 436 million euros (2004 euros). The analysis raises a number of possibilities for further research, so for example access to log book data from boats may give more detailed spatial information on how temperature variations in the ocean impact fishing catch. If it were known which boats from which ports fish where, available temperature data could be used to determine the relationship in more detail. The results could also be extended in another direction, because not all ports are exposed to climate change to the same extent, it may be prudent to consider allocating effort to those ports that are less exposed, other things equal. A planning model could be developed based on some of the results presented here, that could be used to determine the optimal distribution of effort between ports. There is little that small fishing ports can do to stop global warming but there is still much that can be done to adapt to the changing environment, that mitigates the problem of climate induced economic losses.

The analysis could also be extended to consider various sea surface warming scenarios, 1%. 2%, increases in temperature, etc. This is the direction that much of the literature on climate change has taken. However, such analyses often remain highly speculative and fail to answer the question: What has climate change cost us so far? Furthermore, the global nature of climate change means that its impacts are remote for many people, being able to identify the historical cost to particular communities brings home the message that climate change is very real and has real and substantial impacts on people's lives.

Bibliography

Arellano, M. (1987) Computing robust standard errors for within group estimators, *Oxford Bulletin of Economics and Statistics*, 49(4): 431-434.

Arnason, R. (2007) Climate change and fisheries: assessing the economic impact in Iceland and Greenland, *Natural Resource Modeling*, Vol 20, No. 2, pp. 163-197.

Baltagi, B.H. (2008a) Forecasting with panel data, *Journal of Forecasting*, Vol. 27, No. 2, pp. 153-173.

Baltagi, B.H. *Econometric analysis of panel data*, 4th edition, J. Wiley and Sons, 2008b.

BIM (2010) *Killybegs Assessment of the status, development and diversification of fisheries-dependent communities*.

BIM (2012) *Castletownbere: An Economic Survey to Determine the Level of Seafood Activity and Establish its Economic Importance for the Region*.

Brander, K.M. et al.. (2003). Changes in fish distribution in the eastern North Atlantic: are we seeing a coherent response to changing temperature? *ICES Mar. Sci. Symp*. 219: 260-273

Cheung W. L. et al. (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change, *Global Change Biology*, 16(1): 24-35

Cheung W. L. et al. (2012) Review of climate change impacts on marine fisheries in the UK and Ireland, *Aquatic Conserv: Mar. Freshw. Ecosyst*. 22: 368–388

Cook, R.M. and M. R. Heath (2005) The implications of warming climate for the management of North Sea demersal fisheries, *ICES Journal of Marine Science*, 62: 1322-1326

Drinkwater, K.F (2005) The response of Atlantic cod (Gadus morhua) to future climate change, *ICES Journal of Marine Science,* 62: 1327-1337.

Ekerhovd, N-A. (2008) Consequences of climate change for some segments of the Norwegian Fishing Fleet, *SNF Working Paper* No. 36/08.

Farrell, N. et al. (2010) *Sustainable Fishing in Irish waters: Assessment of Current Practices, Policies and Alternative Approaches*, Working paper, No. 165, Discipline of Economics, NUI Galway, Ireland.

Hausman, J.A. and Taylor, W.E. (1981) Panel data and unobservable individual effects, *Econometrica*, 49(6): 1377-1398.

Kell, L.T., Pilling, G.M., O'Brien, C.M. (2005) Implications of climate change for the management of North Sea cod (Gadus morhua), *ICES Journal of Marine Science,* 62: 1483-1491.

Link,P.M. and Tol, R.S.J. (2009) Economic impacts on key Barents Sea fisheries arising from changes in the strength of the Atlantic thermohaline circulation, *Global Environmental Change*, 19(4): 422-433.

Lorentzen, T. and Hannesson, R. (2005) *Climate Change and its Effect on the Norwegian Cod Fishing Industry*, SNF Working Paper No. 07/05

Mac Laughlin, J. *Troubled waters; A social and cultural history of Irelands sea fisheries*, Four courts press, Dublin, 2010.

Marine Institute, *Atlas of the commercial fisheries around Ireland*, Fisheries Science Services, Rinville, Oranmore, Co Galway, Ireland, 2009.

Massetti, E. and Mendelsohn, R. (2012) Estimating Ricardian models with panel data, *mimeo*.

Mendelson, R and Dinar, A. *Climate change and agriculture*, World Bank, 2009.

McIlgorm, .A. Economic impacts of climate change on sustainable tuna and billfish management: Insights from the Western Pacific, *Progress In Oceanography*, Volume 86, Issues 1–2, July–August 2010, Pages 187-191

Nijman, T. & Verbeek, M., (1992) Nonresponse in Panel Data: The Impact on Estimates of a Life Cycle Consumption Function, *Journal of Applied Econometrics*, vol. 7(3), pages 243-57.

Noone, K. Sumaila, R. and Diaz, R.J. (eds.) *Valuing the Ocean: Draft Executive Summary*, Stockholm Environment Institute, 2012.

Perry, A. et al. (2005) Climate Change and Distribution Shifts in Marine Fishes, *Science* 308, 1912.

Planque, B., and Fox, C. J. 1998. Interannual variability in temperature and the recruitment of Irish Sea cod. *Marine Ecology Progress Series*, 172: 101–105.

Planque, B. and T Frédou Temperature and the recruitment of Atlantic cod (Gadus morhua), *Canadian Journal of Fisheries and Aquatic Sciences*, 1999, 56:2069-2077.

Rayner, N.A., P. Brohan, D.E. Parker, C.K. Folland, J.J. Kennedy, M. Vanicek, T. Ansell and S.F.B. Tett, (2006) Improved analyses of changes and uncertainties in marine temperature measured in situ since the mid-nineteenth century: the HadSST2 dataset. *J. Climate*, 19, 446-469.

Rayner, N.A., Parker, D.E., Horton, E.B., Folland, C.K., Alexander, L.V, Rowell, D.P., Kent, E.C. and Kaplan, A., (2003) Globally complete analyses of sea surface temperature, sea ice and night marine air temperature,. *J. Geophysical Research* 108, 4407: 1871-2000.

Reist, J.D. et al (2006) General Effects of Climate Change on Arctic Fishes and Fish Populations, *AMBIO: A Journal of the Human Environment*, 35 (7), 370-380.

Rijnsdorp, A. et al. (2009) Resolving the effect of climate change on fish populations, *ICES J. Mar. Sci*. 66 (7): 1570-1583.

Rose, G.A. (2005) On distributional responses of North Atlantic fish to climate change, *ICES Journal of Marine Science*, 62: 1360-1374.

Stenevik, E.K. and Sundby, S. (2007) Impacts of climate change on commercial fish stocks in Norwegian waters, *Marine Policy*, vol. 31, issue 1, pp. 19-31.

Stock, J.H. and Watson, M.W. (2008) Heteroskedasticity-robust standard errors for fixed effects panel data regression, *Econometrica* 76(1): 155-174.

Sundby, S., and Nakken, O. (2008) Spatial shifts in spawning habitats of Arcto-Norwegian cod related to multidecadal climate oscillations and climate change. *ICES Journal of Marine Science*, 65: 953–962.

Sweeney, J. et al. (2008) *Climate change-Refining the Impacts for Ireland*, Strive report, EPA.

Tol, R. (2002) Estimates of the Damage Costs of Climate Change. Part 1: Benchmark Estimates, *Environmental and Resource Economics* 21, 1 pg. 47

Vilhjalmsson, H (1997) Climatic variations and some examples of their effects on the marine ecology of Icelandic and Greenland waters, in particular during the present century, *Rit Fiskideildar/Journal of the Marine Research Institute*, Reykjavik [Rid Fiskideildar/J. Mar. Res. Inst.]. Vol. 15, no. 1, pp. 1-31. 1997.

Walters, C. and Parma, A. (1996) Fixed exploitation rate strategies for coping with effects of climate change, *Can. J. Fish. Aquat. Sci*. Vol. 53. Pp. &48-157.

Wooldridge, J.M. *Econometric analysis of cross section and panel data*, 2nd edition, MIT, 2010.

Appendix

Fixed effects results for the prediction model. The attrition dummy was automatically dropped due to collinearity.

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Price	1.53886	0.703623	2.1870	0.02932
SST	-0.631538	0.290785	-2.1718	0.03046
PricexBoats	-0.000761901	0.000308734	-2.4678	0.01401
PricexTonnes	-7.23007e-06	4.00035e-06	-1.8074	0.07146
Boats	0.00065369	0.000443015	1.4755	0.14085
Achill	5.78555	0.716661	8.0729	<0.00001
Aran Islands	4.81683	0.709271	6.7912	<0.00001
Arklow	5.78555	0.716661	8.0729	<0.00001
Ballycotton	4.81683	0.709271	6.7912	<0.00001
Ballyglass	5.06331	0.744394	6.8019	<0.00001
Baltimore	6.88919	0.710466	9.6967	<0.00001
Bantry	4.24397	0.704827	6.0213	<0.00001
Bunbeg	4.91609	0.715858	6.8674	<0.00001
Burtonport	6.34394	0.712604	8.9025	<0.00001
Carlingford	5.2764	0.823814	6.4048	<0.00001
Carna	5.26242	0.707303	7.4401	<0.00001
Carrigaholt	5.3365	0.701122	7.6114	<0.00001
Castlegregory	5.29426	0.684167	7.7383	<0.00001
Castletownbere	8.64659	0.719783	12.0128	<0.00001
Cleggan/ Clifden	5.40521	0.720634	7.5006	<0.00001

Clogherhead	6.38286	0.70043	9.1128	<0.00001
Cobh	8.18705	0.743564	11.0106	<0.00001
Courtown	5.36207	0.732379	7.3214	<0.00001
Crosshaven	5.84829	0.693984	8.4271	<0.00001
Dingle	8.19632	0.704785	11.6295	<0.00001
Downings	6.73932	0.7086	9.5108	<0.00001
Dun Laoghaire	5.47359	0.727875	7.5200	<0.00001
Duncannon/St.Helens	6.23881	0.691267	9.0252	<0.00001
Dunmore East	8.64198	0.720873	11.9882	<0.00001
Fenit	6.78003	0.712864	9.5110	<0.00001
Foynes	5.13097	0.702092	7.3081	<0.00001
Galway	5.92753	0.753719	7.8644	<0.00001
Greencastle	7.66718	0.708246	10.8256	<0.00001
Helvick	5.8561	0.707457	8.2777	<0.00001
Howth	8.07602	0.706035	11.4386	<0.00001
Killybegs	10.7225	0.743909	14.4137	<0.00001
Kilmore Quay	6.40165	0.699025	9.1580	<0.00001
Kincasslagh	6.39407	0.807775	7.9157	<0.00001
Kinsale	6.78034	0.699779	9.6893	<0.00001
Lettermore/Lettermullen	4.99808	0.692857	7.2137	<0.00001
Malin Head	6.33722	0.713055	8.8874	<0.00001
Moville	5.42404	0.728132	7.4493	<0.00001
Portmagee	5.90793	0.696418	8.4833	<0.00001
Rathmullan	8.59827	0.747186	11.5075	<0.00001
Rossaveal	8.3557	0.719497	11.6132	<0.00001
Schull	6.45345	0.701549	9.1989	<0.00001
Skerries	6.53553	0.702163	9.3077	<0.00001
Union Hall	7.28764	0.703338	10.3615	<0.00001
Valentia	6.28855	0.690791	9.1034	<0.00001
Wexford	5.36931	0.724424	7.4118	<0.00001
Wicklow	7.49798	0.685629	10.9359	<0.00001
R-squared	0.858718			
F	48.50280			
AIC	886.5022			