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The way the wind blows: Tracing out the demand for Norwegian lobster using instrumental variables

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Abstract

Understanding market demand for common pool resources, such as fish, is important for predicting consequences of sustainable resource management. This article studies how demand functions can be traced out using appropriate supply shifters. We show that wind speed on a fishing trip is strongly correlated with the quantities of Norwegian lobster (Nephrops) available on the Swedish market. Using wind variables as instrumental variables and data on daily average prices and quantities over a 20 year period we estimate the daily aggregate demand for two types of Nephrops. We find that the demand for both types of Nephrops is highly responsive to price changes and that own-price elasticities are two to three times higher than OLS- estimates suggest. In addition, cross-price elasticities show, in contrast to OLS results, that the two types of Nephrops are close substitutes.

Keywords: Demand estimation, Instrumental Variables, Fish markets

JEL: D40; Q21; Q22

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1. Introduction

In August 2016 a Swedish radio station reports that bad weather prevent fishing vessels from leaving port and fish for Norwegian lobster. The reporter fears that it will be shockingly expensive to host the traditional Swedish crayfish parties that are usually held at this time of year and continues: “Only a few fishermen have been able to leave port risking their life and limb. Quantities have been very small and have not harmonized with demand” (Radio P4, 2016). Similarly, in February 2017 a local Gothenburg newspaper report on unusually high prices of Norwegian lobster for the season and claim that these are caused by bad weather, mainly high winds. But the manager of the fish auction in Gothenburg does not believe that this situation will last: “If the weather is good in the weekend supplies of […] Norwegian lobster will increase, and prices will fall” (Göteborgsposten, 2017). On top of fishers risking their lives and crayfish parties being in danger, these stories are exciting objects of analysis for an economist who wants to explore the functioning of markets. The economist sees a market where prices appear to immediately respond to changes in supply. Supply, in turn, is closely related to weather conditions and there is no way that fishers can do anything about the weather.

In general, estimating demand or supply functions using prices and quantities that are observed on the market is difficult since prices are normally determined by demand and supply simultaneously (which will be in equilibrium if the market clears). Using only data on prices and quantities it will be impossible to identify either function. If we want to measure potential changes in demanded and supplied quantities as a response from changes in prices we need to find a method to identify one or both functions. The first attempt to do this was made by Wright (1928) who claimed that elasticities of demand or supply could be computed only when assurance was obtained that one of the functions remained fixed, while the other was changing its position. This, he suggested, could be achieved by introducing additional factors, i.e. other than quantities and prices of the product of interest. With these factors it would be possible to trace out either the demand or the supply function. These factors are what we today call instrumental variables (Angrist and Krueger, 2001).

To estimate the demand function, an additional factor that shifts the supply function, but leave the demand function fixed, must be introduced. Good candidates for supply shifters are factors that affect supply exogenously such as different measures of weather conditions. Production based on natural resources, such as agricultural products or fish, are likely to be affected by weather conditions. Despite this availability the number of studies using weather variables are scarce. The most common approach to estimate demand functions has been to assume that supplied quantities are exogenously given, i.e. that producers do not respond to expected price changes. When this assumption is wrong estimates of price elasticities of demand will be biased. To estimate the demand function in this situation, an additional factor that shifts the supply function, but leave the demand function fixed, must be introduced. Good candidates for supply shifters are factors that affect supply exogenously such as different measures of weather conditions and production based on natural resources, such as agricultural products or fish, are likely to be affected by weather conditions.

Roberts and Schlenker (2013) acknowledge this and use weather as a supply shifter when estimating world demand for corn, wheat, rice and soybeans. However, farmer's produce can be stored which complicates estimations of the demand function using weather variables since current prices of agricultural produce on the market might not reflect current supply if produce from storage is made available on the market. Fish and shellfish, on the other hand, is in many cases fresh produce which is sold not long after it has been caught. Weather conditions today will matter for prices on the market already on the day of the landing or on the following day. Weather variables have been used in a fish market context by Angrist et.al. (2000) and Graddy (2006) estimating the demand for whiting at the Fulton fish market in New York. The results in Graddy (2006) show that using an instrumental weather variable doubles the estimated elasticities of demand.

The price elasticity of demand is most often affected not only by the price of the product itself but also by the demand and associated prices of substitute or complement products. Cross-price-effects could also matter if a product comes in different varieties. Endogeneity of prices has been discussed in the literature estimating demand systems for differentiated products (Berry, 1994, Villas-Boas and Winer, 1999, Dhar et al. 2003, Park et al. 2004, Huang 2015) and in some cases instrumental variables have been used (Villas-Boas and Winer, 1999, Dhar et al., 2003, Huang, 2015). Huang (2015) uses biological stock assessment data to create instruments for estimating the demand for different varieties of blue crab. However, using stock assessments is complicated by the close relationship between stocks and harvest (supply) and it is possible that increased harvest affects fish stocks negatively. Villas-Boas and Winer (1999) and Dhar et al. (2003) use cost variables as exogenous supply shifters. However, using costs of input goods as instruments, such as milk costs for yoghurt production (Villas-Boas and Winer, 1999), is problematic if the input good (milk) enter the demand function as a substitute or complement product.

Knowledge of the price elasticity of demand is of particular interest when it comes to products based on natural resources, such as fish. Fisheries provide a classical example of the 'tragedy of the commons' (Hardin, 1968) and regulation is needed to secure sustainable use of fish stocks (Pitcher et al. 2009). However, introducing more restrictive regulations, such as lower quotas, often meet resistance as revenues may decrease with lower quantities sold, and fisheries authorities frequently set quotas in excess of scientific advice (e.g. Carpenter et al. 2016). On the other hand, there are several examples where reduced quotas and restricted entry to fisheries have increased economic rents through higher landing prices (Townsend, 1990). Knowledge of the price elasticity of demand is crucial to be able to predict the economic losses or gains from changing fish quotas, and consequently important in understanding potential conflicts and tradeoffs in fisheries management.

The aim of this paper is to estimate demand functions of Norwegian lobster (Nephrops Norvegicus. L., henceforth called Nephrops) using instrumental variables based on wind speed, which we argue are defensibly more appropriate than variables used in many previous studies. Using a large dataset of daily landings and prices of Swedish Nephrops in 1996-2016, we show that demand functions for two varieties of Nephrops, creeled and trawled, can be simultaneously identified in a demand system since the two fishing methods are affected differently by weather conditions. This implies that we are able to obtain consistent estimates of both own-price and cross-price elasticities, which we believe has not been made before in the literature. We begin by describing the Swedish Nephrops fishery and our data (section 2 and 3). Then, in section 4, we present our method and choice of instruments. We present our results in section 5, followed by a discussion of our findings in section 6.

2. The Swedish Nephrops Fishery

The Nephrops fishery in Skagerrak and Kattegat is one of the economically most important fisheries in Sweden. With around 1.1 million kilos supplied to the first-hand market, and sold at a value of 134 million SEK (equivalent to around 15 million USD), the Nephrops fishery accounted for approximately 15 percent of the value of total first-hand sales from Swedish commercial fisheries and approximately 50 percent of the shellfish market in 2016 (Statistics Sweden, 2017). As mentioned, two different fishing methods are used resulting in two different varieties of Nephrops sold at the market. The first method entails using trawls that are dragged along the seafloor by a fishing vessel, and the second method uses baited creels that are placed at the bottom of the sea. Creeled Nephrops are larger and less damaged than trawled and many consumers perceive creeled Nephrops as being of higher quality.

Fishing methods are regulated by gear and area restrictions. Since creels placed in trawling areas risk damaging trawls and getting damaged themselves different areas are dedicated to the two fishing methods. Between the Swedish coastline and the so called trawl border, only creel fishing is allowed except in specific areas where trawling with a special sorting grid is permitted (Hornborg et al., 2017). In 2004, the trawl border was moved further off the shoreline thereby increasing the area available for creels by 55 percent (Jonsson and Valentinsson, 2016). Figure 1 shows the areas where Nephrops are fished after the extension of the trawl border.

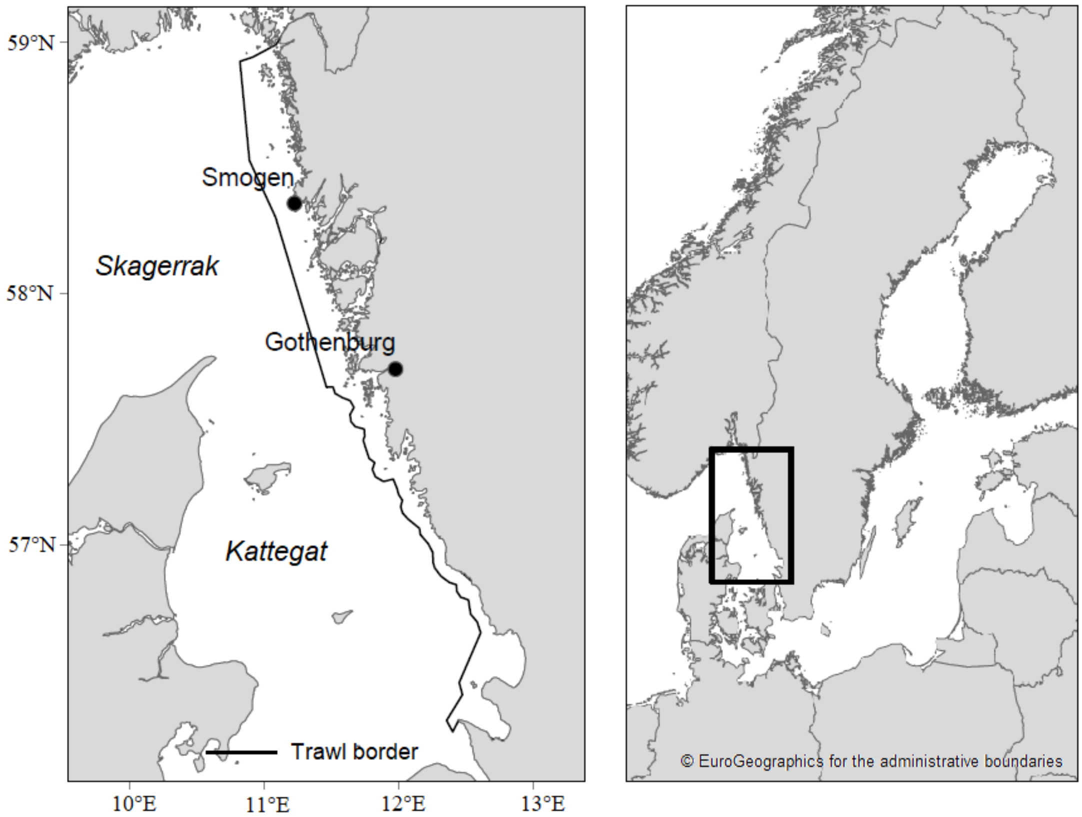

Figure 1: Map of the Swedish west coast where fishing for Nephrops take place after the extension of the trawl border in 2004.

Note: The map is based on data retrieved from Eurostat EuroGeographics (https://ec.europa.eu/eurostat) and SwAM (www.havochvatten.se).

In addition to gear and area restrictions the Nephrops fishery is regulated by quota limitations, fishing licenses and special permits for the fishery. Commercial fishing for Nephrops requires a fishing license where every license gives the fisher the right to use a particular vessel for fishing. Permits for either trawl or creel fishing are also required and the initial quota allocation among vessels is based on quota usage in previous years (SwAM, 2014). Before 2017 the Swedish Nephrops quota was allocated between trawlers using the sorting grid (50 percent), other types of trawls (25 percent) and creels (25 percent) (SwAM, 2015). Vessel quotas were allocated as weekly ratios to each vessel (SwAM, 2016). This changed on 1 January 2017 when yearly individual quotas were introduced. In sum, these regulations limit entry into the fishery and expansion of it and imply that switching between trawls and creels, in addition to requiring purchases of new equipment, is complicated by administrative regulations.

3. Data

We use data on quantities and values of Nephrops reported in sales notes provided by the Swedish Agency for Marine and Water Management (SwAM). All primary receivers of fish are required to register information such as the day of the landing, the quantity of fish sold, the payment received and the quality category of the fish. We also use logbook data with information about gear type to identify the two varieties of Nephrops. The logbook is a compulsory registration of e.g. catches and gears filled in by fishers for each fishing trip. Comparing sales notes and logbook data shows that around 9 percent of landings are not reported in sales notes during our study period (1996-2016).) There is also a small amount of sales that are not possible to match with logbook data (around three percent of the sales quantity).

In our analysis we use daily values and quantities landed on the Swedish west coast on each day between January 1996 and December 2016 as reported in sales notes, i.e. during a period before the yearly individual quotas were introduced. In total, the number of days during this period are 7,671 and we have reports of sales on 6,482 of these days (85 percent of the total number of days). Most of the sales (80 percent in 2016) were taking place at the two major fish auctions in Sweden, Gothenburg and Smogen (see Figure 1), and the activity on these auctions was most intense from Mondays to Fridays with a slight slow-down on Fridays. Average daily prices are calculated as the total daily value divided by the total daily quantity, i.e. prices are quantity-weighted.

Total yearly Nephrops landings as reported in logbooks has varied between 900 and 1100 thousand tons during our study period. Catches have in general been below the Swedish quota set by the International Commission for Exploration of the Sea (ICES, 2018). Trawled Nephrops are dominating the market (76 percent of sales in 2016) although the share of creeled

Nephrops has increased over time, especially after the extension of the trawl border in 2004. There is also considerable variation in quantities of both varieties within each year with smaller quantities of trawled Nephrops in December to April and larger in August and September. The quantity of creeled Nephrops is larger in the spring months (March to May) and smaller in November and December. In particular, there is a sharp increase in trawled Nephrops by the end of the year related to the demand of Nephrops rising before the New Year.

Aggregated price data on a monthly basis (using monthly values divided by monthly quantities) is used to calculate inflation-adjusted prices 1996-2016. Figure 2 shows that prices of Nephrops are highly variable over the year and that there is a regular pattern each year showing that prices are seasonal. Prices of both types of Nephrops are on average higher in the autumn than in spring and are particularly high in July, August and December. Prices have also increased on average during the 20-year period for both types of Nephrops. The difference between the two varieties is clear with a price premium on creeled Nephrops. The average inflation-adjusted price of creeled Nephrops has more than doubled during the time period going from 65 to 130 SEK/kilo between 1996 and 2016. The increase in prices for trawled Nephrops is almost as large going from 55 SEK/kilo to 96 SEK/kilo in the same period.

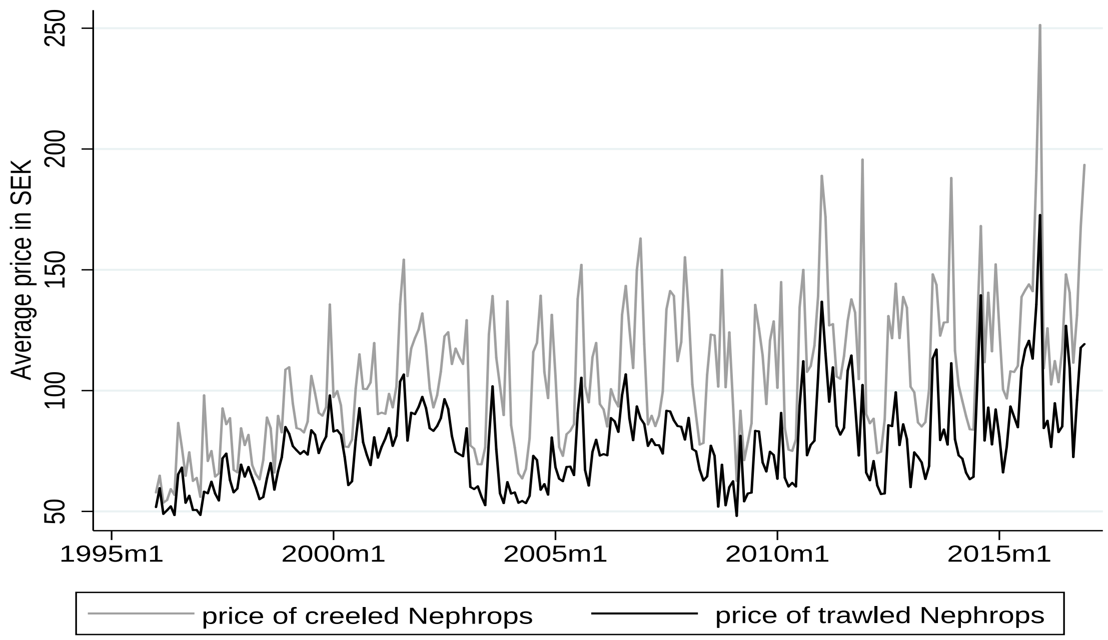

Figure 2: Inflation-adjusted prices (SEK/kilo) of creeled and trawled Nephrops, 1996-2016, January 1996=1.

Figure 2 also shows that prices of creeled and trawled Nephrops are closely following each other. The price premium for creeled Nephrops appear to be higher when prices are higher in general with the price of trawled Nephrops acting as a floor that the price of creeled does not fall below. In sum, we find that prices and quantities are highly varying, both on a monthly and daily basis. These patterns may be caused by fluctuations in demand as well as supply, and there is no way of telling from the figures how price changes affect the demand for the two types of Nephrops. To understand the demand-price relationship it is necessary to isolate supply shifts, which is the topic of the next section.

4. Winds as instruments

In this study, we challenge the assumption that supply is exogenously given, even in the short run. Thus, we believe that fishers react to market prices on a daily basis and adjust their effort in line with their expectations about future prices. In studies investigating fisher behavior expected revenues in the short-run is an important factor in decision making (Nguyen and Leung, 2013; Stafford, 2015; Pfeiffer, 2016; Hammarlund, 2018). Expected revenues have been shown to determine the probability that fishers take part in the fishery on a particular day (Stafford, 2015; Pfeiffer, 2016) and also the probability that fishers choose to continue fishing on a specific fishing trip (Nguyen and Leung, 2013; Hammarlund, 2018). There is no reason to believe that market prices is not an important factor in the daily decision making process in the Swedish Nephrops fishery.

Another factor that is important for decision making in the Swedish Nephrops fishery is the weather conditions. Most vessels taking part in the fishery are small and cannot operate well in adverse weather conditions. Rain, winds, waves, ice coverage, temperature, streams and cloudiness can affect safety onboard and the amount of catches. When the weather is bad catches will be smaller and smaller quantities will be offered on the market on the following days. Our aim is to make use of these weather-related changes in supply and estimate demand functions using weather conditions to shift supply. We start, for simplicity, by presenting a case with a single supply shifter used to identify a single demand function.

Assume that:

$$q_t^s = \alpha_1 p_t + \beta_1 z_\mathrm{t} + u_{1\mathrm{t}} \tag{1}$$

and

$$q_t^d = \alpha_2 p_t + u_{2\mathrm{t}} \tag{2}$$

where t is the time index and the endogenous variables are: q_t^s, the quantity supplied, q_t^d, the quantity demanded and p_t, the price. Assuming that markets clear we have $q_t^s = q_t^d$ (market equilibrium). z_{t} is an exogenous variable in the supply function (the supply shifter) that is uncorrelated with the error terms $u_{1\mathrm{t}}$ and $u_{2\mathrm{t}}$. To identify the demand function we can use the supply shifter z_{t} as an instrument.

Using a weather variable (w) as an instrument we can estimate a first stage as:

$$p_t = \alpha + \beta w_t + u_t \quad (3)$$

where p_t is the log of average price and w_t is a weather variable (f.ex. wind speed or temperature). This regression will measure the variation in price that depends on weather. The predicted values, $\hat{p}_t$, are then used in the demand function (the second stage) as:

$$q_t^d = \gamma + \delta \widehat{p_t} + \varepsilon_t \quad (4)$$

where q_t^d is the demand function which is now identified.

We use hourly wind speeds measured in meter per second from five weather stations spread along the Swedish west coast (Nordkoster A, Väderöarna A, Måseskär A, Vinga A and Nidingen). The data is from the Swedish Meteorological and Hydrological Institute (SMHI). In total we have 791 799 observations of hourly wind speed for the period 1996-2016. We use the average wind speed from the five weather stations for our calculations presented below.

For the identification strategy to be valid the instrument must be independent of the demand function given the price (exclusion restriction) and there must be a non-zero effect of the instrument on prices. The first assumption is an identifying assumption that cannot be tested, but it seems plausible since the demand for Nephrops on a particular day is unlikely to be influenced by wind speed. To investigate the assumption about a non-zero effect of the instrument on prices, we start by plotting average wind speed per day against average price per day (Figure 3) for both type of fishers (trawl and creel). We use observations from 2016 in order to make the graph readable.

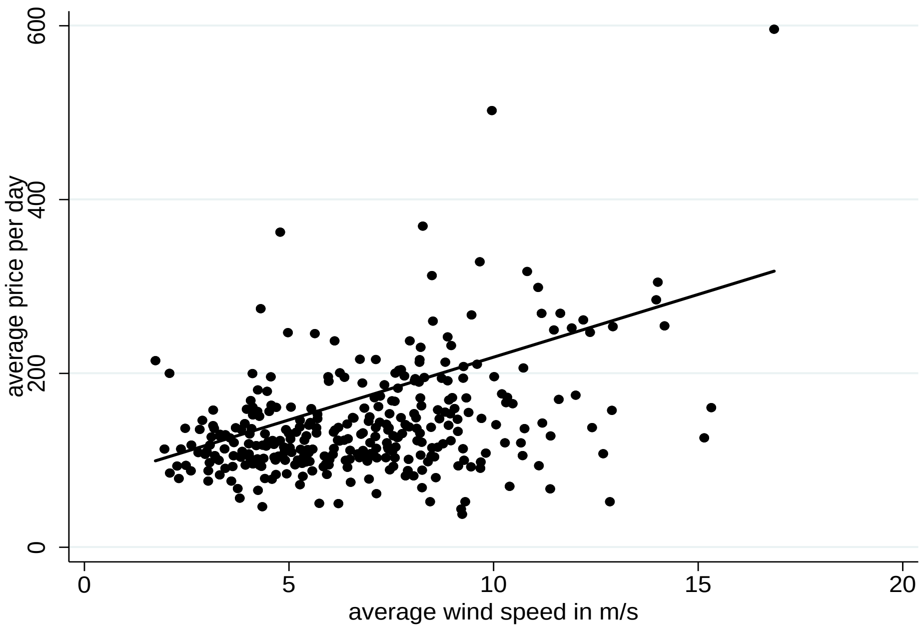

Figure 3: Correlation between daily average price and daily average wind speed in m/s.

We see that the correlation between price per day and wind speed is positive. Wind speed appear to affect prices as expected, i.e. higher wind speed is associated with higher prices, and is thus a potential candidate for an instrumental variable. Outliers in the plot are observed in December which could be explained by increasing demand just before New Year's Eve.

Although wind speed appear to be correlated with prices on a daily basis it is important to consider the timing of fishing activities. For example, it is likely that creel and trawl fishers have different fishing patterns as they differ when it comes to e.g. vessel size, the available fishing area and fishing operations. These differences can be used when defining instrumental variables and we use data recorded in logbooks to investigate such differences in fishing patterns. In doing this, we use observations of fishing activities between 1996-2016 at different times of the day, such as the time of leaving port, the time of setting the first trawl, the time of hauling and the time of arriving back at port. We start by investigating the time of the day when vessels leave port assuming that wind speed at the onset of the trip is important for vessel decision making. The majority of fishers in our dataset report using electronic logbooks where the time of leaving port is reported but vessels below 12 meters are not obliged to report electronically. There is also some misreporting in the data (f.ex. misreporting that results in negative time out at sea or observations with a missing trip identifier). After cleaning the data we have 40 680 observations of times when creel fishers leave port and 194 941 observations of times when trawlers leave port.

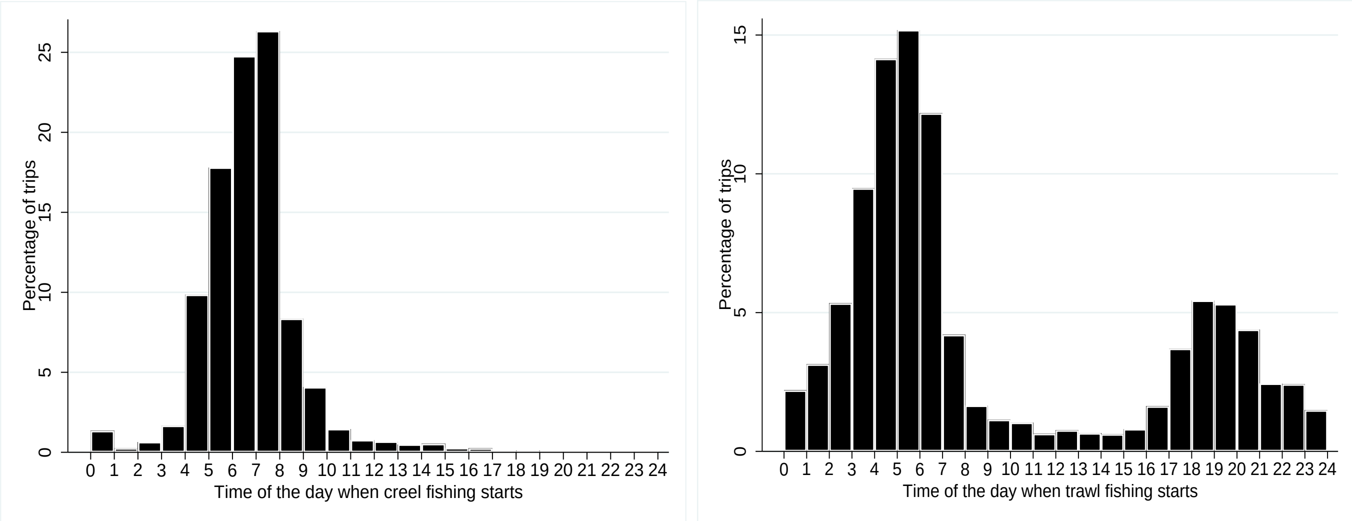

Figure 4: Time of the day when creel and trawl fishing trips start, 1996-2016.

Figure 4 shows that creel and trawl fishing display different patterns regarding the time of the day when the vessel leaves port. Creel fishers in general leave port in the morning with most vessels leaving between 7 a.m. and 8 a.m. Trawl fishers leave either in the evening or in the early morning hours. The most common time to start a fishing trip for a trawler is between 5 a.m. and 6 a.m. but trips also start before and after these times and a significant amount of trips also start between 6 p.m. and 8 p.m. We also check the times when fishers return to port and the number of hours out at sea. Creel fishers normally return at 3 p.m. or 4 p.m. in the afternoon on the same day as they start their trip spending on average nine hours out at sea. Trawl fishers spend on average 19 hours out at sea but the variation is larger than for creel fishers. It is common for trawlers to arrive back at port between 6 p.m. and 8 p.m. in the evening in the day after leaving port.

If wind speed is indeed a good instrument for supply we expect winds at different times to affect the supplied quantities from each type of fishery differently. To investigate this we run two regressions (for our two types of gear i) where quantities (q_i) are regressed on winds at different times:

$$q_i = \alpha + \beta_1 w_{i,m-1} + \beta_2 w_{i,e-1} + \beta_3 w_{i,m} + \beta_4 w_{i,e} + \gamma X + \varepsilon_i \qquad (5)$$

where $w_{i,m-1}$ are observations of wind in the morning before the day that the landing occurred (the average of hourly winds between 1:00 am and 12:00 am), $w_{i,e-1}$ are observations of winds on the evening before the landing took place (the average of hourly winds between 3:00 pm and 12:00 pm), $w_{i,m}$ are observations of wind in the morning on the day that the landing took place and $w_{i,e}$ are observations of winds in the evening on the same day the landing took place.

The time index t is omitted to increase readability. The vector X includes dummy variables capturing day of the week, calendar month and year. From Figure 4 above we expect that creel fisher landings are primarily affected by wind speed on the landing day (predominantly by winds in the morning), and keeping landing day wind constant we do not expect landings to be much affected by the wind on the previous day. Trawl fishers, on the other hand, are expected to also be affected by winds on the previous morning and winds on the previous evening, i.e. $w_{i,m-1}$ and $w_{i,e-1}$, considering that trawlers are out at sea much longer. In addition to individual *t*-tests, an *F*-test of joint significance of the β-coefficients is used to investigate the strength of the instruments. One rule of thumb is that the *F*-statistic should not be below 10 since this may indicate weak instruments (Staiger and Stock, 1997). Table 1 shows the results.

Table 1: The effect of winds on average daily landed quantities, 1996-2016.

Dependent variable is daily quantity of Nephrops …		***… fished with creels.***	***… fished with trawls.***
Coefficients	**Variables**		
β_1	Last morning winds	-2.58	-144.84***
β_2	Last evening winds	-4.38	-73.63***
β_3	Morning winds	-37.57***	-119.01***
β_4	Evening winds	-6.78**	-37.88**
F-test		124.48***	302.61***
N		7670	7670

* for p<.05, ** for p<.01, and *** for p<.001. Year, month and day-of-the-week effects are used in both regressions.

The results confirm our expectations. Creel fishers are mainly affected by winds in the morning of the landings. Winds on the previous day have no additional effects and winds in the evening (from 3 pm) have small additional effects. For example, the morning wind variable suggests that an increase of the average wind speed in the morning by 1 m/s decreases the landed quantity of creeled Nephrops by 38 kilos. As a comparison 485 kilos of creeled Nephrops are landed on an average day during the time period. The F-test of the restriction $\beta_3 = \beta_4 = 0$ shown in column three is highly significant suggesting that the instruments are relevant. Turning to the results for the quantity of trawled Nephrops we see that in contrast to creel fishers winds on the day previous to the landing are the most important, but also that the winds on the landing day have significant effects. Similar to the results for creel fishers, winds on the evening of the landing day are of less importance. The F-test of joint significance of all beta coefficients ($\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$) produce a highly significant test statistic indicating that the instruments are relevant.

Although we believe that the Nephrops fishery is very likely to be affected by wind variables it is possible that there are additional effects from other weather variables that could also be used as instruments. Hornborg et al. (2017) state that creel fishing is more sensitive to rough weather (winds) whereas, trawling, is also affected by cold weather. This is also supported by Feekings et al. (2015) who find that landings per unit effort of trawlers is lower when the weather is cold. For this reason we also add the average temperature on the day of the landing and the average temperature on the day before the landing to equation 1 in the trawler equation (data is from SMHI). However, we find that temperatures do not have an additional significant effect on trawler landings and are thus not further considered as instrumental variables.

In sum, the discussion above supports the idea of using different wind variables as instruments when estimating the demand for creeled and trawled Nephrops. We propose using two instrumental variables: morning winds, $w_{i,m}$ and evening winds, $w_{i,e}$, for the price of creeled Nephrops, and four instrumental variables: morning winds, evening winds, winds on the previous evening and morning, i.e. $w_{i,m}$, $w_{i,e}$, $w_{i,m-1}$ and $w_{i,e-1}$, for the price of trawled Nephrops. The first stage equation for each type of Nephrops is then estimated as:

$$p_t = \alpha + \beta' \boldsymbol{w_t} + \gamma' \mathbf{X}_t + u_t \tag{5}$$

where p_t is the log of average price on day t, w_t is a vector of wind variables and $\mathbf{X}_t$ is a vector of controls for year, month, day-of-the-week and the week leading up to New Years' Eve included to capture other effects that are related to demand. This regression will measure the variation in price that depends on winds. The predicted values, $\hat{p}_t$, are then used in the demand function (the second stage) as:

$$q_t^d = \pi + \delta \hat{p}_t + \boldsymbol{\theta}' \mathbf{X}_t + \varepsilon_t \tag{6}$$

Finally, we estimate a two-equation demand system including both types of Nephrops specified as:

$$\boldsymbol{q_t^d} = \boldsymbol{\Phi} + \boldsymbol{\Delta}' \mathbf{p_t} + \boldsymbol{\Theta}' \mathbf{X}_t + \boldsymbol{\xi_t} \tag{7}$$

where the $\boldsymbol{\Delta}$ vector captures both the own-price and cross-price elasticities. The system estimation is carried out using GMM (see more on this below).

5. Results

We start by presenting the results from estimations of equation 6 and for comparison purposes we also show the results from ordinary least squares (OLS) regressions. The first stage regressions showing the explanatory power of the instruments are presented in the Appendix, Table A1. Regarding the time series properties of the variables, augmented Dickey-Fuller tests (Dickey and Fuller, 1979) show that the null hypothesis of non-stationarity can be firmly rejected at the 5 percent level for all variables in the model. However, the residuals from the regressions show signs of autocorrelation with clear spikes in the estimated autocorrelation function at lag 7. We therefore present the results from OLS and instrumental variables (IV) estimation using heteroscedasticity and autocorrelation consistent (HAC) standard errors (the HAC approach is implemented with the Bartlett kernel and lag length is determined using Newey and West's (1994) optimal lag-selection algorithm).

Table 2 presents results for the demand of creeled and trawled Nephrops. Column 2 contains the OLS-estimates and column 3 contains estimates where wind variables (as defined above) are used as instrumental variables. We see that IV-estimates are significantly higher than OLS-estimates suggesting that the demand for both types of Nephrops is considerably more responsive to price increases than what the OLS-estimates suggest. The estimate from the IV-regression on creeled Nephrops indicate that a price increase by one percent decreases demand by 3.2 percent. This is almost three times as large as the OLS estimate. We find similar results for trawled Nephrops where the coefficient more than doubles when instruments are used. A price increase of one percent decreases the demand of trawled Nephrops by 5.1 percent in the model with instruments.

Table 2: OLS and IV estimates of the demand for creeled and trawled Nephrops

	Without instruments	**With instruments**
Dependent variable is log quantity of Nephrops fished with creels		
$\ln(\text{price})^{creel}$	-1.15***	-3.24***
N	6010	6010
Dependent variable is log quantity of Nephrops fished with trawls		
$\ln(\text{price})^{trawl}$	-2.33***	-5.10***
N	6005	6005

* for p<.05, ** for p<.01, and *** for p<.001. Year, month and day-of-the-week effects are used as well as a dummy variable for the week leading up to New Year's Eve (time controls).

Comparing the results for creeled and trawled Nephrops we see that own-price elasticities are higher for trawled than for creeled Nephrops. Although we cannot directly compare the results from the two separate equations we can look at the confidence intervals of the coefficients and see if they overlap. Using the estimates from the IV-regressions we find that the 95 percent confidence interval for the own-price elasticity of creeled Nephrops ranges between -3.5 and -3.0 whereas the corresponding confidence interval for trawled Nephrops is between -5.4 and -4.8. This suggests that the price elasticity of demand is higher for trawled than for creeled Nephrops (this will be formally tested in the demand system below). Since both demand models are overidentified, i.e. the number of instruments exceeds the number of endogenous variables, it is possible to test the validity of the instruments using tests of overidentifying restrictions (e.g. Greene, 2003). The test we use was suggested by Wooldridge (1995) and is robust to heteroscedasticity and autocorrelation (through pre-whitening) in the error terms. In both demand equations the resulting test statistic from Wooldridge's test is found to be lower than the critical value suggesting that the instruments are not correlated with the error terms.

To analyze how prices of creeled and trawled Nephrops interact we also estimate cross-price elasticities, where the log price of trawled Nephrops also appearing in the equation for the demand of creeled Nephrops and vice versa (i.e. we estimate equation 7). We use the same instrumental variables as above to account for the fact that the own-price variable also appear in the supply equation. We assume that there is no supply-side substitution between the two varieties of Nephrops as is discussed in section 2 and 3, i.e. that fishermen cannot switch between gears in response to short-term (daily) price changes. In order to see the importance of using instrumental variables, the estimates when excluding and including the instruments are presented in column 2 and 3 of Table 3, respectively. The demand system without instrumental variables is estimated by the SURE approach and the instrumental variable specification is estimated using a two-step GMM estimator with HAC robust errors to account for cross-equation dependence.

Table 3: System estimation of the demand for creeled and trawled Nephrops with and without IVs

	Without instruments	**With instruments**
Dependent variable is log quantity of Nephrops fished with creels		
$\ln(\text{price})^{creel}$	-1.31***	-5.61***
$\ln(\text{price})^{trawl}$	-0.07	2.91***
Dependent variable is log quantity of Nephrops fished with trawls		
$\ln(\text{price})^{creel}$	-1.38***	4.24***
$\ln(\text{price})^{trawl}$	-1.50***	-9.49***
N	5550	5550

* for p<.05, ** for p<.01, and *** for p<.001. Year, month and day-of-the-week effects are used in both regressions as well as a dummy variable for the week leading up to New Year's Eve (time controls).

As can be seen, the results differ markedly depending on whether or not instrumental variables are used in the estimation. The naive SURE-estimation without instruments indicates that creeled and trawled Nephrops are complements in the demand equation for trawled Nephrops, which is at odds with our expectations given the similarity of the two goods. However, looking at the second column, the results from the IV-estimation suggest that the creeled and trawled Nephrops are close substitutes. For example, a decrease in the price of trawled Nephrops has a large negative effect on the demand of creeled Nephrops. Thus, demand can easily switch to trawled Nephrops should the price of creeled Nephrops deviate from the price of trawled Nephrops too much. The same reasoning goes for the demand of trawled Nephrops. The two varieties are thus close substitutes on the market. Similar to Table 2, the own-price elasticity for trawled Nephrops is larger than for creeled Nephrops; a Wald test of equality of coefficients gives a test statistic of 27.1, which is significantly higher than the 3.84 critical value of the $\chi^2(1)$ distribution.

The market for Nephrops is undoubtedly a part of a larger market for shellfish and it is possible that prices of other species also interact with prices of Nephrops. We have omitted other species from the analysis since our primary interest is in estimating the demand elasticities for Nephrops. An important species on the Swedish west coast is prawns (sold boiled and fresh at the first-hand market) accounting for around 50 percent of shellfish sales (Statistics Sweden, 2017). We add the price of prawns to our equations to see if this affects our estimates (Appendix, Table A2). The results show that an increase in the price of prawns affect the demanded quantity of Nephrops, i.e. prawns and Nephrops are substitutes. The cross-price effects of prawns are also smaller than cross-price effects between the two types of Nephrops, which can be expected. More importantly, the estimates of own- and cross-price effects of the two types of Nephrops do not change much by including prawns in the demand system.

Although we believe that it is unlikely that winds affect demand directly it might be argued that bad weather such as heavy rain, which may be correlated with wind speed, affects consumption of Nephrops negatively (for example, if fewer people will go out to restaurants in the weekends). Even if this is the case it is unlikely that bad weather on the west coast will have an effect on demand. First, the time lag from the day of fishing until the day of consumption makes it unlikely that the weather at the day of fishing is the same as the weather at the day of consumption. Second, Nephrops are sold at the auctions on the west coast of Sweden but they are transported and consumed all over the country. However, as a further robustness check we collect additional information about daily rainfall from the SMHI weather stations along the Swedish west coast (data of precipitation from 6 a.m. to 6 a.m. the next day). The rain variable is then included as an additional control in the demand equations to capture possible demand effects of changing weather conditions. The results (not reported) show that the coefficient on the rain variable is statistically insignificant in both equations and the price elasticities remain unaffected.

6. Discussion

It is well known that market demand for fishery products has the potential to influence the sustainability of fish resources (e.g. Reddy et al., 2013; Sethi et al., 2010). Also when a quota system is in place introducing more restrictive catch limitations often meet with resistance and quotas are frequently set in excess of scientific advice (Carpenter et al. 2016). A better understanding of market demand could help policy makers predict how markets would be affected by possible management measures. This knowledge is important to understand and foresee potential conflicts and tradeoffs in fisheries management. Identifying demand functions in a market where only equilibrium quantities are observed is an old and challenging problem. More than 90 years ago Philip Wright (1928) wrote that estimations of supply and demand functions require the use of instrumental variables unless it can be assumed that one of the functions does not change its position, or as he put it: "in the absence of intimate knowledge of demand and supply conditions, statistical methods for imputing fixity to one of the curves while the other changes its position must be based on the introduction of additional factors." (Wright, 1928, p. 311-312).

However, studies estimating demand functions rarely use instrumental variables since appropriate instruments are hard to find. First, a challenge is to find instrumentals that are strong enough to trace out the desired function. For example, it is not uncommon to encounter problems with weak instruments when estimating demand functions for agricultural products using different measures of weather variables such as temperature and precipitation (e.g. Roberts and Schlenker, 2013). In contrast, we present instrumental weather variables that are strong in the sense that they are clearly related to the decisions made by the fishers. The quantity fished on a particular day is strongly correlated with wind speed according to our estimations.

Second, it is difficult to find instruments that can be argued to be truly exogenous. Previous studies have used e.g. yield per acre (for agricultural products) and fish stocks (for fish products), but such instruments are problematic since they may themselves be a function of prices. Higher prices on agricultural products may induce farmers to choose higher sowing intensities or encourage farmers to expand production to less fertile fields, which would invalidate the exogeneity of the instrument. Similarly, higher fish prices may encourage fishers to harvest more intensively, which may in turn impact fish stocks. We argue that random weather conditions such as wind speed are defensibly more exogenous and the robustness checks performed in this paper support this assumption.

Our results show that the demand for both types of Nephrops is highly responsive to price changes. The price elasticities are much higher than what OLS results without instruments suggest. This is in line with Graddy (2006) who finds that instrumental variables approximately doubles the estimated price effect in her study of sales of whiting at the Fulton fish market in New York. Graddy reports elasticities around -1 suggesting that fisher's revenues will not be much affected by price changes. We find much larger elasticities. This means, for example, that a negative supply shock will cause only a small rise in price but a relative large fall in quantities demanded. Thus, in contrast to Graddy (2006), we find that when bad weather reduce harvest, revenues will decrease as increased prices will only marginally compensate for lower supplied quantities. This line of reasoning is also true for other external factors affecting supply of Swedish Nephrops, such as changed quotas and more restrictive regulations regarding fishing licenses.

Another result is that the price elasticity is higher for trawl fishers than for creel fishers. Although it is difficult to draw any conclusions this difference could be related to the characteristics of the two types of Nephrops. Creeled Nephrops are regarded as of higher quality by consumers and could for this reason be somewhat less price sensitive. Finally, our results show that creeled and trawled Nephrops are close substitutes. This might be expected since we have two varieties that are much alike, but we show that estimating a system with the two varieties *without* instrumental variables fails to show that this is the case. This emphasizes the importance of identifying the demand function correctly also when cross-price elasticities are estimated.

Since we use daily data of quantities and prices the demand functions that we are estimating must be regarded as short-termed. We control for changes over the years and over the months which means that we control for elasticities of demand that change over time. Increasing incomes of the population might for example increase the demand for shellfish if it is regarded as a luxury product. There could also be an increase in awareness of the effects of the different fishing methods on the environment causing an increase in the demand for creeled Nephrops over time. Estimating long-run demand is outside the scope of this study and would be more challenging since finding appropriate instrumental variables are likely to be difficult.

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Appendix

Table A1: The first stage

Dependent variable is daily average price of Nephrops …	***… fished with creels.***	***… fished with trawls.***
Last morning winds		0.03***
Last evening winds		0.01***
Morning winds	0.04***	0.01***
Evening winds	0.01***	0.01***
N	6010	6005

* for p<.05, ** for p<.01, and *** for p<.001. Year, month and day-of-the-week effects are used in both regressions as well as a dummy variable for the week leading up to New Year's Eve.

Table A2: System estimation of demand for Nephrops including prawns

	Without instruments	**With instruments**
Dependent variable is log quantity of Nephrops fished with creels		
$\ln(price)^{creel}$	-1.63***	-6.34***
$\ln(price)^{trawl}$	-0.09	3.20***
$\ln(price)^{prawn}$	0.40***	0.64***
Dependent variable is log quantity of Nephrops fished with trawls		
$\ln(price)^{creel}$	-1.56***	5.53***
$\ln(price)^{trawl}$	-1.64***	-11.64***
$\ln(price)^{prawn}$	0.44***	1.00***
N	5087	5087

* for p<.05, ** for p<.01, and *** for p<.001

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