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A Case Study of Technological Switching and Technological Lock-In in the French Fisheries Sector: Why is Sustainable Change so Difficult?

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Abstract :

Many sectors such as the fishery show classic examples of technological lock-in and path dependence, even though some economists might predict smooth switching toward technologies that are more cost effective and sustainable. We use ideas from the evolutionary economics and public choice literatures to explain why trajectories of technological change, especially in fisheries, may not be smooth at all, but rather punctuated. The interest of technological change and switching behavior for fisheries economists and managers stems from the fact that control of effective effort, often necessary for sustainable management of the resource, remains a central management problem for that sector worldwide, even in developed countries. However, various policies put in place by governments to support the fishing sector, and often put in place to "correct" for certain market failures, may inadvertently produce other "nonmarket" failures, which result in technological lock-ins which are unsustainable. For example, the trawling technique was widely promoted in France in the 1970s and 1980s. Path dependency developed in such a way that the preferred choice of new entrants into the fishery was this technology. Technological lock-in occurred on the trawling technique as the trawling sector also became more politically active, making it ultimately the most widely used technique in the French fisheries sector in the Atlantic. Switching away from this technology has not taken place even with poorer economic performance of that technology. This paper also discusses the influence of state subsidies on the adoption of trawling. Even if trawling was a major innovation in fisheries in the past, its potential for technological adaptations or minor innovations is limited now. These limitations are more obvious during periods of increasing energy prices, especially in the absence of state aid. However, due to collective choice phenomena, switches to more sustainable technologies will occur more slowly.

Résumé :

Plusieurs secteurs, tel que celui des pêcheries, offrent des exemples de verrouillage technologique et de dépendances au sentier, alors même que les économistes s'attendent à un changement régulier vers une technologie plus efficace en termes de coûts et plus soutenable. Nous nous appuyons sur la littérature évolutionniste et des choix publics afin d'expliquer pourquoi les trajectoires du changement technologique, en particulier dans les pêcheries, peuvent ne pas être régulières, mais au contraire discontinues. L'intérêt des économistes et des gestionnaires pour le changement technologique et le comportement face au retour des techniques est lié au contrôle de l'effort réel, souvent nécessaire pour une gestion durable de la ressource. Le contrôle de l'effort reste le problème essentiel de la gestion des pêches à l'échelle mondiale, y compris dans les pays développés. Toutefois, de nombreuses mesures publiques mises en place par les gouvernements pour soutenir le secteur des pêcheries, afin de «contrecarrer» certaines défaillances du marché, peuvent déboucher involontairement sur d'autres défaillances «non marchandes», se traduisant par des verrouillages technologiques non-soutenables. Par exemple, la technique du chalutage fut largement diffusé en France dans les années soixante-dix et quatre-vingt. Un sentier de dépendance s'est développé tel que les nouveaux entrants dans la pêcherie optaient pour cette technologie. Un verrouillage technologique s'est produit sur la technique du chalutage rendant ce secteur politiquement important, et finalement la technique la plus répandue parmi les pêcheries françaises de l'Atlantique. Un changement de technologie n'a donc pu survenir, même en présence de faibles performances économiques. L'article traite de l'influence des subventions étatiques liées à l'adoption du chalutage. Même si cette technologie fut une innovation majeure dans les pêcheries par le passé, les adaptations techniques potentielles ou les innovations mineures sont désormais limitées. Ces limites apparaissent clairement dans les périodes de coûts énergétiques croissants, notamment en l'absence d'aides étatiques. Toutefois, en raison du phénomène de comportements collectifs, les changements vers des technologies plus soutenables se déroulent avec lenteur.

1. Introduction

Many fisheries world-wide are over-exploited, mainly because of declining stocks and growing effective fishing effort, often helped along by subsidies and jobs programs offered by governments. Considering this unsustainable behaviour by the private and the public sector, economists might expect that their recommendations would be taken seriously; usually a shift towards techniques and practices which are more resource conserving, and a systematic control on effort, possibly using market forces. There is some global evidence (Sumaila *et al.*, 2008) that this is happening. However, there are also other cases where the practices and the techniques adopted in the past have managed to persist, even though there is mounting evidence that, even from the standpoint of very practical criteria such as fuel efficiency, these technologies should be abandoned. This paper discusses that phenomenon by reviewing information on the costs of passive gear versus the production costs of trawls, or mobile gear, in the French fishery and comparing that to their exit and switching behaviour. All countries have examples of unfair and inefficient subsidies, and government-caused technological lock-in. But we can say that this French case study demonstrates more clearly than most how an active role by the state to resolve one set of market failures may actually impede normal processes of technical switching, thus making the sustainable management of fisheries more difficult.

There are policies which can encourage sustainable or unsustainable trajectories of technological change. An example of this is taken from the French fisheries, where we find evidence that the subsidy policies in place for fuel may have favored mobile gear technologies and large scale fishers. Over a long period of time, the “bending” of the trajectory in this direction by subsidies, along with passive technology adoption, learning behavior, and the influence from the general economy, exhibits inertia that can only be overcome by large exogenous shocks. In this case, that large shock was the rising costs of fuel, but also at issue is whether a fuel subsidy policy in this case really is sustainable.

This paper presents a general explanation of why technological switching occurs. We then extend this explanation, taken from both evolutionary economics and public choice theory, to explain why switching may not happen, or may happen as "punctuated equilibria". Next, empirical evidence of fuel price increases inducing a switch from mobile to fixed gear is presented. Finally, we show that the presence of the subsidy policy for fuel would dampen the readjustment to the alternative (and seemingly dominant) technical pathway. We conclude the paper by discussing some of the reasons why policy makers in France, and elsewhere, may be motivated to enact these subsidies, even though it is generally understood that doing so is neither sustainable nor efficient.

2. Switching techniques : flexible or punctuated ?

Technological re-switching has usually been presented in terms of how easy or difficult it is for firms in an economy to respond to changing relative input prices. Some of the focus of these discussions is also on capital malleability. Technological switching and re-switching, and the conditions under which it happens, has been a part of three important debates in economics (see for example Han and Shefold, 2006). One debate arose in part from divergent views about the malleability of capital in an economy, called the Cambridge debate. Sraffa (1960) predicted that, under assumptions of malleable capital in economies with multiple sectors, there can be multiple re-switching, suggesting that changes from one technology to another will be relatively smooth.

The neoclassical explanation of switching behavior (Stiglitz, 1973) relies of the effects of changing relative factor prices and marginal productivities, subject to underlying changes in technology. When capital costs are high, compared to labor, firms will tend to switch to more labor intensive techniques and vice versa.

A third explanation can be developed based on the insights of evolutionary economics. Nelson and Winter (1982) and Dosi (1988) sought to ground explanations of economic growth in the micro-behavior of the firm. Technical change was presented as adaptations which are evolutionary. In a later survey article, Nelson (1995) argues that the evolutionary economics research related to path dependency and technological lock-in was a response to the unrealistic assumptions that neoclassical economists make with regard to the relatively fluid response of the firm to relative factor prices. Further, while Nelson's work, and the work of other evolutionary economists, deals mainly with incentives internal to the firm leading to path dependency and technological lock-in, there are also powerful incentives external to the firm, in the form of the economic and political relations between other firms and governments. Although Nelson (1995) argues that the co-evolution of law, technology and industry structure had only been touched lightly in the writings on how the law evolves, there are examples of attempts to link these (England, 1994; Metcalfe,1994; Cowan and Gunby,1996; Carillo-Hermosilla, 2006; Faber and Frenken, 2009). These issues were also being explored as inefficiencies arising from "non-market failures" (Wolf ,1978; 1986;)[1], which have also been the subject of research by specialists in organization theory and Public Choice Theory. Public Choice Theory, according to one of its founders, James Buchanan (1984), is the study of "government failure", in the same way that neoclassical economics was concerned with "market failure". This research agenda explains path dependency and lock-in as the results of the organizational particularities and operating objectives of agencies, and how they react to their constituencies. While technological switching certainly occurs, modern economic descriptions of technological change suggest rather "punctuated equilibria[2]". If that is the case, then examining how technological trajectories get stuck, and why, would seem an important applied research topic in economics. Two powerful and complementary explanations are those relating to the internal workings of the firm which cause stickiness (evolutionary economics), as well as the interactions between these firms and other outside institutions (public choice explanations).

Capital, under these explanations is often not fungible. The firm and firm managers are not always adequately described by the neoclassical representations of technology and firm managers are well-aware that spending resources for coercion and lobbying of public officials can be a substitute for innovation and internal change.

The interest of technological change and switching behavior for fisheries economists and managers stems from the fact that the control of effective effort remains one of the central management problems for that sector, and for many managers, the most elusive. It is well-

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[1] Thanks to one of the reviewers for calling our attention to this reference.

[2] The tendency for a system to stay in one state for a long period of time, only to lurch rapidly to another equilibrium in response to mounting pressure from exogenous forces. This term and mechanism was first elaborated in evolutionary biology as an alternative to gradualism by Niles Eldrige and the evolutionary theorist S.J. Gould. However parallels drawn by both Gould and Nelson to complex economic processes are not simply metaphorical.

known (Le Floc'h and Fuchs, 2001), that technical change in fisheries is largely passive[3], and may occur for reasons which are related to growth in the general economy.

2.1. A Simple Switching Model

Metcalfe and Steedman (1972), in early work that preceded explicit evolutionary economics modeling, examine the effects of a positive return on capital on the question of technique choice, especially in situations where such switching might be considered "perverse", such as when a productive process starts out favoring techniques that are comparatively more capital intensive than labor intensive, but then suddenly these factor intensities (and the favored technique) reverse. We use this model to motivate our discussion of the reasons for path dependence in the fishery, because the model can be represented graphically. Another reason is that, in our case study, the actual techniques under consideration are capital intensive (trawling) or labor intensive (fixed gear), which provides a ready analytical picture.

In the Metcalfe and Steedman model, the production of commodities takes place in an input/output framework, where net outputs in the economy are produced using, among other factors, capital goods. A positive rate of profit is earned on the value of capital. The economy is in autarky with two homogeneous primary inputs; land (L) and labor (I) both at full employment. These factors are not produced by the economy, and are thus constraints on production. The simple economy produces two commodities, which are both capital goods and goods for final consumption.

To produce the two commodities, the economy uses a number of technically efficient fixed coefficient processes, known at the beginning of the process. The production is annual, and all capital stocks are used up and must be replaced at the beginning of each production period. Each technique is either land intensive in the production of commodity 1 (C1) or labor intensive for commodity 2 (C2).

Variations in the consumption patterns of members of the economy and owners of factors are not represented in this model. Aggregate consumption patterns depend only on relative commodity prices and perfect competition is assumed. These authors assumed that the economy is in a state of stationary long term equilibrium and that comparisons between techniques are being made in this context. One unorthodox assumption with regard to the perfect competition assumption is that the rate of profit on capital goods reflects payments to that factor, and that these values are positive. Finally, a higher ratio of rents to wages does not necessarily lead to using a more labor-intensive technique of production, but rather can lead to the use of a more land-intensive technique.

Following Metcalfe and Steedman, the fixed factor production model of commodities 1 and 2, C_1 and C_2 is;

$$C_1 = a_{11}*C_1 + a_{21}*C_2 + a_1*I + A_1*L \qquad (1)$$

$$C_2 = a_{12}*C_1 + a_{22}*C_2 + a_2*I + A_2*L \qquad (2)$$

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[3] In technological change literature, adoption is either active (a fisherman invents a new way to retrieve gear through concerted R&D), or passive (a fisherman buys a GPS device to replace Loran C, a laptop computer for the boat, or overhauls his engine to replace the one that is worn out: In the process he/she gets cheaper, better, or longer lasting equipment by making these routine changes).

Where C_1 is commodity one

a_{11} and a_{21} are respectively inputs of commodity one and two to produce one unit of output C_1

C_2 is commodity two

a_{12} and a_{22} are respectively inputs of commodity one and two to produce one unit of output C_2

L is quantity of land

l is quantity of labor

The a_{ij} parameters are fixed, and the sum of the two parameters associated with Land (A_i) and labor (a_i) is unity. This assumption means that each technique is only based on one process for each commodity (land-intensive or labor-intensive), and inputs (land and labor) are fully used. Prices of the commodities in competition are given by:

$$P_1 = (a_{11}*p_1 + a_{21}*p_2)(1+r) + w*a_1 + W*A_1 \qquad (3)$$

$$P_2 = (a_{12}*p_1 + a_{22}*p_2)(1+r) + w*a_2 + W*A_2 \qquad (4)$$

Where P_1 and P_2 are respectively monetary prices for commodities C_1 and C_2

Where r = the payment to capital, w = the wage for labor, and W = the rent for land, all interpreted as input prices[4].

The relative price of the commodities reduces to:

$$\frac{P_1}{P_2} = \frac{(1-a_{22}(1+r))(a_1 + A_1 W/w) + a_{21}(1+r)(a_2 + A_2 W/w)}{(a_{12}(1+r))(a_1 + A_1 W/w) + (1-a_{11}(1+r))(a_2 + A_2 W/w)} \qquad (5)$$

In other words, the output price ratios of the commodity are a function of the input price ratios, as well as r, the payments to capital. After differentiating this with respect to W/w, and rearranging terms according to which commodity we wish to examine, we obtain a wage rent frontier between w and the two arguments r and W. This allows us to look at the wage-rent frontiers for the production of different commodities produced, say C_2, which is intensive in labor:

$$w2 = \left\lfloor \frac{\det(I-(1+r)A)}{a_2(1-a_{11}(1+r)) + a_1 a_{12}(1+r)} \right\rfloor - \left\lfloor \frac{A_2(1-a_{11}(1+r)) + A_1 a_{12}(1+r)}{a_2(1-a_{11}(1+r)) + a_1 a_{12}(1+r)} \right\rfloor W2 \qquad (6)$$

I is a 2X2 identity matrix and A is the matrix of fixed factor coefficients.

The intuitions of these relations are shown in Figure 1. Equation 6, produced for commodity 2 with only one technique (technique a), shows inverse relationships between W2 and r, and w2 and r. When r tends towards 0, W2 and w2 attain maximum values.

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[4] This linear equation for prices has been discussed during the Cambridge debate and the occurrence of reswitching. The nature of the reswitching of techniques was the central question in six papers published in The Quaterly Journal of Economics in November 1966.

The model with Two Techniques: What happens when there are two possible techniques for producing good 2? A number of results can be expected, subject to the relative magnitudes of the input parameters. One possible result, shown in Figure 1, is that the more capital intensive technique, **a**, would dominate on the wage-rent frontier, from 0 to r1. It would be replaced by the wage intensive technique **b** from r1 to r2, but would revert to the capital intensive technique from r2 to r3, and beyond R_{max} for technique **b**, would be dominated by technique **a** again. This analysis suggests that in competitive economies with multiple factors of production and several techniques, there would be incentives to switch techniques depending upon relative factor prices. This essentially neoclassical perspective we present might cause us to expect that technical switching occurs often. For example adding a third primary factor to this simple model provoked the case of "perverse switching". Real life observations of firms operating in some competitive economic environments suggest that they are sensitive to changing relative factor remunerations, especially when driven by innovation and education.

2.2. When Subsidies Favor a Technique: The Fisheries Example

Using the Metcalfe and Steedman model, we explore the impacts of a subsidy favoring the capital intensive technique, in this case the trawl technology. In agriculture and in fisheries as well as in other parts of the economy, techniques become dominant in sectors (Ruttan, 1978).

Firms using these dominant techniques may be faced with pressure to switch techniques, brought on by changing relative factor prices. However, a less costly approach may be for these dominant firms to lobby governments for special considerations[5], in lieu of undergoing the costs of switching, which can also imply learning a technique, and disposal of older capital goods. In Figure 1, the situation of no fuel subsidies (solid lines) and subsidies (dotted lines) is explored with the framework developed by Metcalfe and Steedman. The dotted lines are the wage (w2)-rent (r) frontiers with fuel subsidies for trawls (**a**) and fixed gear (**b**) compared to the case without subsidies. Fuel subsidies for the fishing fleet in France benefitted all techniques that use engines. However, these fuel subsidies comparatively favor the capital intensive technique (trawling), so the range of r over which capital intensive techniques dominate will be enlarged, even though both techniques benefit from the subsidy. This is exemplified by the reduction of the switching zone where technique b, the fixed gear technique, would dominate (from r3-r1 to r1s to r3s).

There are even more practical complications that make this neoclassical view of switching less fluid than imagined. Whereas the preceding analysis of technical switching assumes malleable capital, the problem in fisheries as in other sectors is that capital comes into production and is durable. The durability of that capital may pose a number of problems to the investor, especially in the face of changing costs of other factors. As will be seen in the case of the French fishery and elsewhere, policies of rationalization revealed that the actual residual value of capital fixed in the trawl fleet was far lower than the owners of that capital had expected. Since markets for excess capital are not fluid either, there was a strong incentive for younger members of the fleet and owners of newer vessels to petition their government for relief. New entrants and younger operators may be financially more vulnerable than end-career fishermen. In France, that relief came in the form of fuel subsidies. Such subsidies have the effect of pushing the date at which this non-malleable capital will be disposed of into the future. Therefore, it may be that

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[5] These often take the form of import tariffs on competing goods, subsidies for the input that is the most costly, guaranteed loans, and production credits. We will call these "subsidies". In the French case, we focus on the fuel subsidy, although there are others.

technological lock-in may not be just the result of wage-price frontiers of a dominant technique, but rather a political-economic result of producers trying to preserve the values of their capital investments by affecting the competitive conditions of factor markets. A proactive government was enlisted to this end. This might explain why, in real economic sectors, there may be several techniques operating at once, and why one technology may be dominant from one time to the next for reasons having little to do with efficiency or sustainability. In this way, the non-malleability of capital may be one reason why subsidy programs seem persistent. However, these programs help to ensure technological lock-in, and may not ultimately be sustainable.

The subsidy therefore has two effects. It masks or occults techniques which may be more efficient over prevailing rates of r, w, and W, thereby slowing down switching. Second, and more importantly, it helps to fix non-malleable capital onto development pathways for the sector which are difficult to change, because of technological lock-in. The next section presents a case study, and the following section discusses the real-life implications of these policies.

3. French fisheries of the Atlantic coast

Vessels using the trawling technique are distributed over most of the fishing grounds listed by the International Council for the Exploration of the Sea (Figure 2), while boats using passive methods (fixed gear) are concentrated along the coast of the Bay of Biscay (VIIIa and VIIIb). The coastal zone, limited to 12 nautical miles from the shoreline, is mainly fished by smaller vessels of under 12 meters.

Analysis of the evolution of fleets allows a preliminary assessment of the impacts on fleet production and the economic situation of different categories of management measures (mainly fish stock conservation measures). Capacity reduction programs are one type of fishery management measure which has had strong impacts on fleets. The analysis of changes in the structure of the French Atlantic fishing fleet provides insights into the impacts that capacity reduction programs adopted over the study period (1990-2005) had on these fleets (Guyader *et al.*, 2007) . One of the most important access regulation measures enacted by the French government at the end of the 1980s was the “Permis de Mise en Exploitation” or Operation Permit system, a *de facto* limited entry scheme. Following limited entry, several decommissioning schemes were carried out in France during the 1990s, as part of the Multi-Annual Guidance Programs for capacity reduction.

Depending on the fleet and the year, buyback policies reduced vessel numbers by 44% from 1990 to 2005 (Figure 3). The size of the commercial fishing fleet located on the Atlantic coast has decreased, from 3675 vessels in 1990 to 2053 in 2005, with a large decline in 1991 due to the implementation of the first decommissioning scheme by the French State to reduce potential fishing capacity. The largest percentage reduction over the period was among vessels using the trawling technique (46%), whereas the number of users of alternative fishing techniques decreased by 43%. The trawl technique represents 40 to 47% of the total vessels, depending on the year, and reciprocally, passive methods were used on greater numbers of fishing vessels. However, the number of large trawlers (over 20 meters) has not changed as much, from 194 to 176 vessels over the study period. The impact of fleet reduction policies therefore varied widely according to the different users of the trawling technology. The number of trawlers less than 20 meters decreased from 1309 units in 1990 to 636 units in 2005.

Measured from engine power in kW (Figure 4), which is directly related to fuel consumption, the reduction in capacity appears less dramatic for the largest trawlers (-8%) compared to smaller trawlers under 20 meters (-47%). Overall, decommissioning schemes explain a large proportion of the reduction in the size of the fleet, although other motives led vessels to exit. Hence, fleet buyback policies contributed significantly to the reduction in size of these fleets. During the study period, the contribution of the entire fleet of trawlers in terms of kW declined from 64% to 60% of the total capacity. Only the largest trawlers increased their relative capacity (or fishing effort) from 17% in 1990 to 24% in 2005, despite the buyback schemes implemented by the French government (Guyader *et al*. 2007).

Structural measures to encourage exit from the fishery implemented during the nineties seem to have had limited effects on reducing the fishing capacity of the larger trawler vessels. Fishers do not respond identically to management measures such as buyback programs, or other external factors like rising fuel costs. If fishermen are assumed to behave rationally, the number of adopters of the trawling technique should have been declining in the face of high expected fuel costs, because the trawl technique is more energy intensive than passive techniques, assuming fishermen do not receive any financial help from their government. The measure of the relationship between fuel consumption and the value of landed catch is one of several eco-systemic indicators providing some empirical evidence of the differential in fuel use of the competing fishing methods. Most studies devoted to energy intensity in fisheries have concluded that large fishing units, using mobile gear, are more energy intensive (Ellingsen and Aanondsen, 2006; Tyedmers *et al.*, 2005).

The value of the investment decision (from the trawling to the passive technology) has to cover the cost of the project, mainly if the investment is irreversible. Therefore, switching is optimal only when the rise in fuel price is large enough, as suggested by the literature on real options and hysteresis (Dixit and Pindyck, 1994). Moreover, the possible influence of the broader context in which vessel owners made their decisions regarding investment must be considered, and in particular the impact of the fiscal regime on these decisions (Le Floc'h *et al*., 2011). One of the major challenges is to study the investment dynamics under the real assumption of non-malleability of capital (Munro 2010). Technological switching, from the trawling to the passive technology, is an expected result only when the rise in fuel price is large enough over a long period of time. The best way to measure this magnitude is the level of fuel subsidies in fisheries. Sumaila *et al.* (2008) have estimated fuel subsidies for 86 countries, and found a potentially strong impact of these on the sustainability of fisheries.

For this reason, analyzing fishers' behavior with regard to increasing fuel costs provides new insights into the understanding of technical change, especially between trawlers and users of passive fishing gear.

4. Data and methods

4.1. Data

Data are available for a variable sample of owner-operators of single fishing vessels over the period 1998-2005. The dataset contains varying number of observations from year to year due to the collection of economic data organized by the Regional Observatory of Fisheries in Brittany, with a maximum of 179 observations in 2003 and a minimum of 167 in 2000. Two major sources of economic information, namely bookkeeping and auction market data, are used simultaneously by the Regional Observatory for the same set of vessels.

Large gaps can be observed between both sources, according to different marketing channels used by fishermen (auction market, direct sales to consumers and contractual relations with processors). Individual data are validated from the indicator of gross revenue (approximated by figures supplied by bookkeeping and by landings value in the market base) only when the gap between the bookkeeping of the firm and the fish auction market source is less than 20%. Variable samples represent approximately a global sampling rate of 8% of the commercial fishing fleet located on the Atlantic coast (2053 boats in 2005, as shown in Figure 4).

Descriptive statistics on technical parameters for trawlers and passive units are given for the year 2005 (Table 1). Economic information for these fishing companies was provided by the Regional Observatory of Fisheries in Brittany, from bookkeeping databases that include landings value, and operating and financial costs. These data cover the 1998-2005 period for a varying sample of fishing vessels (trawlers and alternative techniques), classified according to length classes, (four classes for trawlers and two for vessels using passive techniques). Trawlers over 20 meters are very sensitive to fuel costs and are considered in this research as the reference units. Fuel use, expressed in physical units (metric tons or MT), is directly proportional to length classes (from 32 MT for trawlers less than 12 meters to 464 MT for the biggest trawlers).

We studied fishers' behavior with regard to fuel consumption using an econometric model of fisher fuel consumption by fleet class as a function of , among other things, energy costs. Fishers' behavior with regard to increasing fuel costs depends on the fishing method used. Moreover, the potential production capacity is constrained by energy requirements. Length and fishing method are assumed to be relevant standards to study the path dependency of each fleet segment *vis à vis* fuel consumption. The aim of the econometric work was to measure the gaps between fleet classes and the larger trawlers of 20-25 meters, assuming these are more dependent on the energy input.

4.2. Modelling approach

Stepwise regression methods were used to select the model. The choice criterion is based on Akaike and Bayesian information criteria (Greene 2003). We explain fuel consumption in quantity (liters) for each vessel (i), expressed in log (log (fuel$_{i,t}$)), as a function of gross revenue computed one and two years before (log(GR$_{i,t-1}$) and log(GR$_{i,t-2}$)), technical characteristics (deviation from average gross tonnage, GT, and engine power, kW, building year), and dummy variables for fleet segments with "trawlers <12 m" =1 and 0 otherwise, "trawlers 12–16 m" =1 and 0 otherwise, "trawlers 16–20 m" =1 and 0 otherwise, "passive <12 m" =1 and 0 otherwise, "passive >12 m" =1 and 0 otherwise. The segment of "trawlers 20-25 m," as the reference segment, is in the intercept. Stepwise methods were used to test the full model for six years (from 2000 to 2005). The best model, expressed through a semi-logarithmic equation, includes the explanatory variable gross revenue one year before (GR_{t-1}) in log, deviation from kW and all dummy variables. Mathematically, the estimated equation for our panel data set is:

$$\begin{aligned} \log(Fuel_{i,t}) &= \alpha + \beta \log(GR_{i,t-1}) + \gamma dkW_{i,t} + \lambda_1 trawlers < 12m_{i,t} + \lambda_2 trawlers 12-16m_{i,t} \\ &+ \lambda_3 trawlers 16-20m_{i,t} + \lambda_4 Passive < 12m_{i,t} + \lambda_5 Passive > 12m_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (7)$$

Introducing observed gross revenue as an explanatory variable lagged one year ($GR_{i,t-1}$) is empirically justified. It is assumed that fishermen allocate a fraction of current revenue to compensate potential higher level of fuel costs. In this way, they exhibit rational behavior, expecting volatile fuel prices. This assumption is verified for a few fishing companies (mainly adopters of the trawling technique), who hold some part of revenue in reserve in their business account, in order to reduce the impact of fuel cost increases in the following year.

Under this assumption, fishermen are not considered as myopic, and their decisions are based on the actual and future (or expected) price of fuel. Two main theories of economic expectations can be called to support this behavior; adaptative expectations and rational expectations (Berck and Perloff, 1984). Our model is consistent with the theory of adaptive expectations (Cagan, 1956).

As the model associates explanatory variables expressed in log ($GR_{i,t-1}$) and others in linear form (deviation from kW and dummies), we are cautious in the interpretation of the semi-logarithmic equation results. Hence, β is an elasticity coefficient of $Fuel_{i,t}$ with respect to $GR_{i,t-1}$, as the percentage change in $Fuel_{i,t}$ for a percentage change in $GR_{i,t-1}$. One can expect a positive coefficient, meaning an increase in fuel consumption when gross revenue increased in the previous year. Concerning linear variables, their coefficients ($\gamma, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5$) give the instantaneous growth rate and are not directly elasticity coefficients as β[6].

5. Results

5.1. How Fishers Responded to Increasing Fuel Costs

Fishers in this study have had their fuel costs affected in three ways. First, fuel costs have experienced temporal fluctuations related to world demand and supply. Second, fuel costs confronted by fishers are lower, because of their tax exemption. Third, fuel costs have been affected by emergency measures resulting from the fishermen lobbies. The evolution of monthly fishing fuel prices (Figure 5), excluding taxes, shows two peaks occurring in 2000 (€0.31 per litre) and in 2005 (€0.40 per litre).

Rising fuel prices might have enhanced the substitution effect between fishing techniques in 2000 and more particularly in 2005 due to the higher dependence of trawlers on fuel compared to boats using passive techniques. If taxes were to be included, reflecting what a typical consumer in France would pay for fuel, then prices would be two or three times higher than shown. However, fuel prices paid by the fishing as well as the agricultural sectors in France are already subsidized, and have been throughout the period considered in this study. In addition, the French government has also implemented state aid programs as a result of pressure from fishermen's lobbies. This double scheme of subsidies is therefore composed of more standard measures and the emergency measures put in place in 2000, as well as more recently in 2005 and 2006.

The best model, selected with a stepwise method, includes inflated gross revenue ($GR_{i,t-1}$) adjusted for inflation, the year before, deviation from mean kW, and dummy variables (Table 2). All variables, apart from the intercept and the dummy "trawlers16–20 m", are significant at the 1% level. That means that there is different behavior in terms of fuel consumption between the largest trawlers (over 16 meters) and other segments of the fleet.

Expressed in logarithms, the influence of gross revenue is positive and proportional to the fuel consumption the year after. An increase of 10% in gross revenue, or landings value, leads to a

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[6] Halvorsen and Palmquist (1980) suggest taking the antilog of the linear coefficients and subtracting the value of 1 from them to obtain elasticity measures.

higher fuel consumption of between 7%-10% the following year. As expected, fuel needs are lower for smaller trawlers and vessels using passive gear.

During the study period, from 1998 to 2005, fuel prices adjusted for inflation increased by 7% a year, estimated from the instantaneous growth rate α ($lnfuel\_price = \alpha.year + \beta$). However, these prices already include a fuel subsidy. Fuel cost as a percentage of turnover or gross revenues, increased from 16% in 2004 to 23% in 2005 for the trawlers (Observatoire Economique Regional des Pêches de Bretagne, 2006). If we consider emergency state aid as well, the effect of that price increase was largely neutralized (17% in 2005). The impact on passive gears was less severe, ranging from 5% of turnover in 2004 to 8% in 2005. With emergency state aid, these costs too were largely neutralized in 2005 (6%).

The results derived from the econometric model confirm that fishers did not change their techniques in the face of increasing fuel prices. Average fuel uses (in metric tons) have barely changed over the period, 2000-2005. Fuel consumption has slightly increased for the biggest trawlers (over 16 meters), the instantaneous growth rate is by +0.04% a year for the 20-25 meters and +1% a year for the16-20 meters. Consequently, the statistics given in Table 1 for the year 2005 suggest static behavior, mainly explained by subsidies for fuel. Theoretically, a permanent increase in fuel price might change fishers' behavior by reducing fishing time (Ward *et al*., 2005) or inducing technique switching. Empirically, the econometric analysis shows a reinforcement of the path dependency favoring a technological lock-in on the trawling technique. The estimations results show no statistically significant differences between the 16-20 meter trawlers and the trawlers of 20-25 meters from 2003, since the dummy variables are insignificant. Both segments can then be considered as the reference segment. The technology that benefits most, not only from tax exemptions but also from emergency aid, is the trawl technology. This is because the governance system in the French fishery considers the larger (20-24 meters) trawlers as the dominant segment, and these firms effectively work as a lobbying group with a strong influence on public decisions. Consequently, the State aid for fuel has reinforced the technological lock-in on the trawling technique, mainly used by the larger operators.

5.2. Why Weren't the Biggest Units Affected?

The impact of fuel costs on the comparative desirability of alternative technological trajectories should be considered when evaluating policy choices. In the current economic situation however, one could ask why a switching phenomena was not more apparent or accelerated away from trawling techniques, which are more capital and energy intensive, especially compared to passive methods, even with all of the subsidies. The reason why technical change has not occurred in the biggest units is because subsidy policies for fuel comparatively favor trawling technologies and large scale fishers.

6. Discussion

Our analysis shows that fuel support regimes have delayed the process of technical change in the French fishing industry by slowing down the exit of vessels or encouraging them to keep fishing with trawl gear. However, if fuel prices continue to rise (Brook *et al*. 2004), another fuel price crisis will confront the bigger trawlers, which will likely incite vessel owners to lobby harder for more aid. If a political solution is not possible, the economic viability of trawling would decline, leading to switching. On the other hand, the French government has historically been disposed to act on behalf of agricultural producers and fishers (Mesnil, 2008). So persuasive are these particular pressure groups in France that they have even caused their administrations to adopt policies that appear to be at odds with EU policy.

Fishers in this particular case took an early interest in upholding a special regime designed to limit the impact of high fuel prices. The fund, as originally conceived, was to have been a type of insurance partnership, where fishers were to make contributions to a common fund that would have paid out during periods of high fuel prices. This tool has been used in dealing with other risky markets. The financial contributions from fishermen, not surprisingly, were relatively low, compared to the compensation that was ultimately given to stakeholders. The French government then stepped in, and has been the main contributor to this fund, which was originally created by fishermen. In a sense, fishers have forced the French government to protect them, even though that same government knows very well that their policy is neither sustainable, nor is it likely to be upheld as legal, since state aid is not supposed to be permitted to support such a compensation mechanism (European Commission 2006).

In cases like this, the state encourages technological lock-in through *ad hoc* policymaking, often, as Olson (1965) has argued, in favour of a small, well-organized group who has a lot to lose or gain. In this case, that group is represented by the more capital intensive technique, which is not necessarily the most profitable. This option can be socially sustainable as long as other fishermen using alternative techniques also benefit from the subsidies. It also requires that the larger public, often unaware of the policy or unconcerned about it, is willing to accept the inequities that might occur with the policy. However, the more serious problem with *ad hoc* policy-making is that an artificially induced technological lock-in is provoked, which can be non-sustainable in the long run (ecologically and economically). In this case, the trawling technique should by this time have been demonstrably an inferior technique, because it wastes economic resources, especially natural stocks[7]. Also at issue is whether fuel subsidy policies to any sector can be justified, given what is known about the broader effects of fossil fuel use. There might be justifiable cases, but we suspect that they will not be wide-spread. And if they are not, then our discussions about capital non-malleability and the relation that has to technological trajectories highlights a crucial question: “…how can new lock-ins of inefficient or undesired technologies be avoided?” (Van den Bergh, 2007).

One way of avoiding or minimizing these effects might be for fisheries economists to explore more broadly the literature in economics, especially relating to theories of collective action, public choice, and evolutionary economics (Wilson, 2007), and then to build these ideas into policy recommendations. The development of fisheries governance structures that take account of both the positive and negative effects of coercion and lobbying needs critical attention, especially as it is connected to the question of technological trajectory. Certainly, changes in governance that force discussions of policies through public hearings assisted by the press cannot hurt. On the other hand, government assistance in the areas of promoting education and entrepreneurial innovation among fishers that is necessary for new and sustainable technologies should be favored.

Public agencies everywhere played a major role in promoting technological lock-in on the trawling technology from the beginning of the 1960s, which turned out to be highly fuel-dependent compared to passive gears. Trawling has often been cited as a major innovation in

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[7] One persistent difficulty with trawling is how to make the technique targeted enough to reduce the accidental catch of juveniles, endangered species, and non-target species, while at the same time minimizing damage to ecosystems. While progress has been made, these serious issues remain.

fisheries (Standal, 2007; Meuriot, 1986; Whitmarsh, 1978). However, its potential for technological adaptations or even minor innovations is now doubtful without state aid, especially during periods of increasing energy prices. That conclusion is confirmed in this study, using detailed comparisons of the financial viability of the different classes of vessels prepared by the European Commission by year. In the 2007 annual report, based on economic results of 16 national fleets (including French fishing fleets) for 2005, it stated that: “the trawling fishing vessels, intensive in consumption of fuel, have suffered the biggest economic deterioration in 2005. … In contrast, vessels using passive gears have showed some economic improvement” (European Commission, 2007).

This paper has presented evidence of the relative economic disadvantage of the trawling technology for certain segments of the French fleet; however, fuel subsidies may have diminished the incentive to switch technology. Current policy has resulted in increased use of energy by larger high-powered vessels, because the State aid had effectively reduced operating costs, thus indirectly off-setting increased fuel prices paid by fishermen. Policies of this type may well subvert other important policies aimed at sustainability of fish stocks and fleet rationalization.

Acknowledgments

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References

Berck, P., and J.M., Perloff. 1984. An open-access fishery with rational expectations. *Econometrica*, 52(2):489-506.

Brook, A.M., R. Price, D. Sutherland, N. Westerlund, and C. André. 2004. Oil prices developments: drivers, economic consequences and policy responses. OECD, Economics Department Working papers, Paris, No.412, 51p.

Buchanan, J.M. 1984. Politics Without Romance: A sketch of Positive Public Choice Theory and its Normative Implications. In J.M. Buchanan and R.D. Tollison, eds. *The Theory of Public Choice II*, The University of Michigan Press, 457p.

Cagan, P.. 1956. The monetary dynamics of hyperinflation. In M. Friedman, ed., Studies in the quantity theory of money, University of Chicago Press.

Carrillo-Hermosilla, J. 2006. A Policy Approach to the Environmental Impacts of Technological Lock-in. *Ecological Economics,* (58) 717-742.

Cowan, R, and P. Gunby. 1996. Sprayed to Death: Path Dependence, Lock-in and Pest Control. *The Economic Journal*, Vol. 106, No. 436 (May, 1996), pp. 521-542.
URL: http://www.jstor.org/stable/2235561

Dixit, A., and R. Pindyck. 1994. *Investment under uncertainty*. Princeton University Press, Princeton, NJ.

Dosi, G. 1988. Sources, procedures, and microeconomic effects of innovation. *Journal of Economic Literature* 26: 1120–1171.

Ellingsen, H., and S.A. Aanondsen. 2006. Environmental impacts of wild caught cod and farmed salmon: A comparison with chicken, *International Journal of Life Cycle Assessment*, 1(1):60-65.

England, R.W. 1994. Three Reasons for Investing Now in Fossil Fuel Conservation: Technological Lock-In, Institutional Inertia, and Oil Wars. *Journal of Economic Issues*, Vol. 28, No. 3 (Sep., 1994), pp. 755-776.

European Commission. 2007. *Economic performance of selected EU fishing fleets*. Annual Report, (http://www.ccr-s.eu/transfert-pdf/InfoCCR51/Annual_Economic_Report.pdf), Brussels, 98p.

European Commission. 2006. Fund for the prevention of risks to fishing: Invitation to submit comments pursuant to Article 88(2) of the EC Treaty, (EC) No C91/05, Brussels, 5p.

Faber, A., and K. Frenken. 2008. Models in evolutionary economics and environmental policy: Towards an evolutionary environmental economics, *Technological Forecasting and Social Change*, 76:462-470

Greene, W. 2003. *Econometrics*. Fifth edition, Pearson Education, New-Jersey, 946p.

Guyader, O., P. Berthou, and F. Daurès. 2007. Decommissioning Schemes and Capacity Adjustment: A Preliminary Analysis of the French Experience. In *Fisheries Buybacks*, ed. By Curtis R., Squires D., Blackwell Publishing, 288p.

Halvorsen, R., and R. Palmquist. 1980. The interpretation of dummy variables in semilogarithmic equations. *The American Economic Review* 70 (3): 474-475.

Han, Z., and B. Schefold. 2006. An Empirical Investigation of Paradoxes (Reswitching and reverse Capital Deepening) in Capital Theory. *Cambridge Journal of Economics*, 30 (5): 737-765.

Le Floc'h, P., F. Daurès, M. Nourry, O. Thébaud, M. Travers, and S. Van Iseghem. 2011. The influence of fiscal regulations on investment in marine fisheries: A French case study. *Fisheries Research* 109: 257-264

Le Floc'h, P., and J. Fuchs. 2001. Economics of science in fishery sector – The European case. *Marine Policy* 25: 133-142.

Mesnil, B. 2008. Public-aided crises in the French fishing sector. *Ocean and Coastal Management* 51: 689-700.

Metcalfe, J.S., and I. Steedman. 1972. Reswitching and primary input use. *The Economic Journal*, 82 (325): 140-157.

Metcalfe, J.S. 1994. Evolutionary Economics and Technology Policy. *The Economic Journal*, 104(425): 931-944.

Meuriot, E. 1986. Fishing fleet replacement: The French policy from 1945 to 1983. *Marine Policy* (10:4):294-309.

Munro, G.R.. 2010. *The Way Forward: Getting the Economic Theory Right, The First Steps*. IIFET 2010 Montpellier (France) Proceedings.

Nelson, R.R., and S.G. Winter. 1982. *An evolutionary theory of economic change*. Harvard University Press, Cambridge, MA, 437p.

Nelson, R.R. 1995. Recent Evolutionary Theorizing about Economic Change. *Journal of Economic Literature*, Vol. XXXIII (March), pp. 48-90.

Observatoire Economique Regional des Pêches de Bretagne. 2006. Résultats des flottilles artisanales 2004/2005, http://www.univ-brest.fr/gdr-amure/ressources/rapport_obs_breton2005.pdf,, 62p.

Olson, M. 1965. *The Logic of Collective Action*. Harvard University Press.

Ruttan, V. 1978. Induced innovation, evolutionary theory and path dependence: sources of technical change. *Economic Journal* 107:1520-1529.

Sraffa, P. 1960. *The Production of Commodities by Commodities-Prelude to a Critique of Economic Theory*, Oxford University Press.

Standal, D. 2007. The rise and fall of factory trawlers: an eclectic approach. *Marine Policy* 32: 326-332.

Stiglitz, J.E. 1973. The Badly Behaved Economy and the Well-Behaved Production Function' in Mirrlees, J.A. and Stern, W.H. (eds.) *Models of Economic Growth*, London, pp 117-137.

Sumaila, U.R., L. The, R. Watson, P. Tyedmers, and D. Pauly. 2008. Fuel price increase, subsidies, overcapacity, and resource sustainability. *ICES Journal of Marine Science* 65:832-840.

Tyedmers, P., R. Watson, and D. Pauly. 2005. Fueling global fishing fleets, *Ambio*, 34(8):635-638.

Van den Bergh, J.C. 2007. Evolutionary thinking in environmental economics. *Journal of Evolutionary Economics* 17: 521-549.

Ward, J,, P. Mace., and E. Thunberg. 2005. The relationship of fish harvesting capacity to excess capacity and overcapacity. *Marine Resource Economics* 19: 525-529.

Whitmarsh, D. 1978. Stern trawling: a case study in technological change. Centre for the Economics and Management of Aquatic Resources, Portsmouth, UK, Research Paper (1), 21p.

Wilson, J.R. 2007. Challenges and opportunities for fisheries managers in developing countries: a case for economic eclecticism, *Int. J. Global Environmental Issues*, Vol.7, Nos. 2/3, pp. 205-220.

Wolf, C. 1978. *A theory of "non-market failure": Framework for Implementation Analysis*. January, Rand Corporation, P6034, 63p.

Wolf, C. 1986. Market and Non-market Failures: Comparison and Assessment. *Journal of Public Policy*, 19.

Figures

Figure 1. Technique choice in the production of commodity 2 and “perverse” switching, without subsidies (solid lines) and with subsidies (dotted lines).

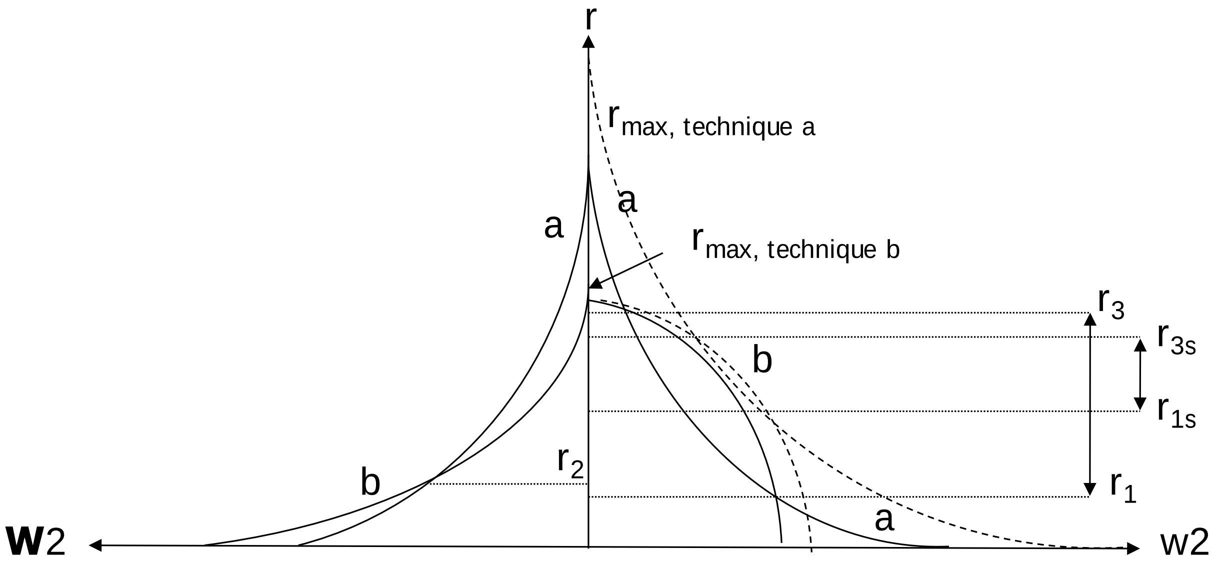


Figure 2. The Bay of Biscay fisheries, VIIIa and VIIIb. (Source: International Council for the Exploration of the Sea).

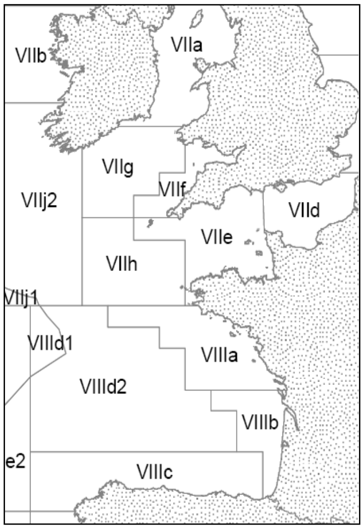


Figure 3. Evolution of fleets in number, from 1990 to 2005, describing the impact of decommissioning schemes. (Source: IFREMER)

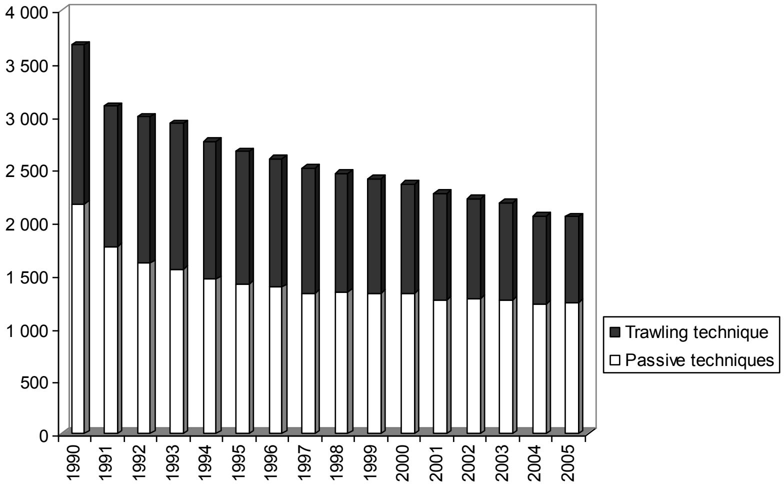


Figure 4. Evolution of fleets in kW, expressed in percentage, from 1990 to 2005. (Source: IFREMER)

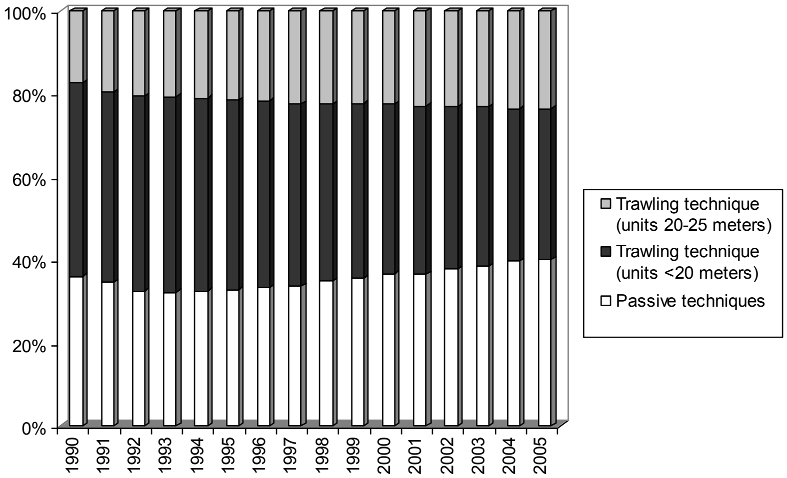
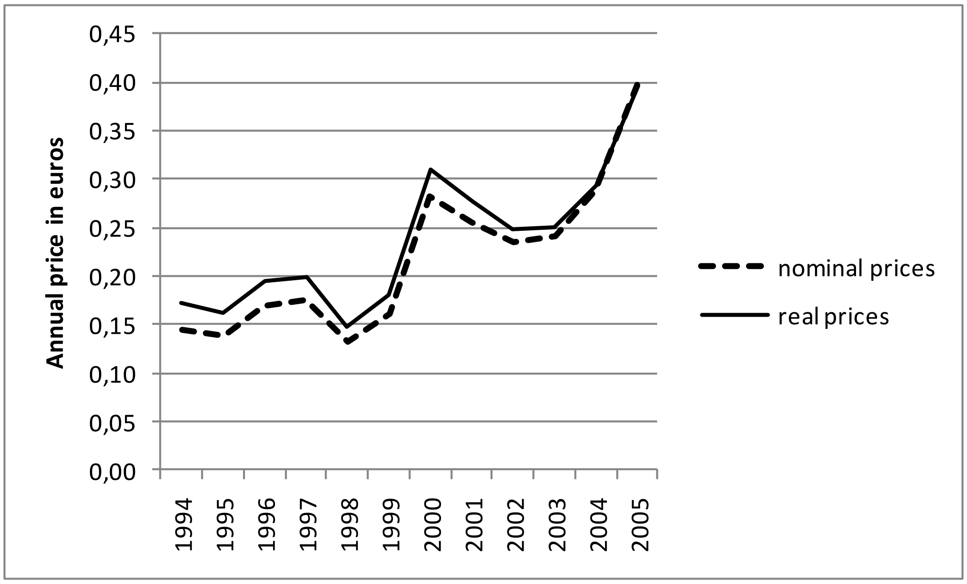


Figure 5. Annual price per litre of fuel for the French fishing sector, 1994 to 2005. (Source: Coopérative Maritime du Pays Bigouden)



Tables

Table 1. Technical characteristics, annual sample in 2005

	Samples (in 2005)	Age (years)[a]	Length (meters)	Engine power (kW)	Fuel use in 2005 (MT)
Trawlers >20m.	33	18	22	430	464
		(5.7)	*(16.4)*	*(5.7)*	*(4.5)*
Trawlers 16-20m.	20	22	17	302	265
		(5.5)	*(13.9)*	*(6.9)*	*(3.1)*
Trawlers 12-16m.	38	23	15	225	141
		(3.1)	*(11.8)*	*(4.3)*	*(1.8)*
Trawlers <12m.	27	27	10	120	32
		(3.5)	*(8.3)*	*(3.3)*	*(1.1)*
Passive >12m.	9	19	13	173	55
		(8.5)	*(10.6)*	*(5.6)*	*(3.1)*
Passive <12m.	48	21	9	124	21
		(2.9)	*(6.6)*	*(2.9)*	*(1.5)*
All vessels	175	22	14	226	162
		(3.2)	*(2.9)*	*(1.8)*	*(0.9)*

[a] Mean values of the samples and *t-value* in brackets are given for the age (years), length (meters), engine power (kW), and metric tons of fuel use (MT). (Source: IFREMER-SIH and Observatoire économique régional des pêches)

Table 2. Results of the econometric model (dependent variable; log of fuel consumption) [a]

	Year 2000	*Year 2001*	*Year 2002*	*Year 2003*	*Year 2004*	*Year 2005*
R^2	0.94	0.94	0.93	0.94	0.92	0.87
n	167	168	178	179	175	175
Intercept	1.39	1.66	1.30	1.18	0.71	-0.07
t-value	*(3.2)*	*(4.1)*	*(3.1)*	*(2.8)*	*(1.4)*	*(-0.1)*
$\log(gr_{t-1})$	0.72**	0.68**	0.74**	0.76**	0.83**	0.97**
t-value	*(9.9)*	*(10.0)*	*(10.5)*	*(10.9)*	*(10.2)*	*(8.7)*
$Dev(e_{kw})$	0.35**	0.37**	0.34**	0.31**	0.25**	0.28**
t-value	*(6.8)*	*(7.6)*	*(6.9)*	*(6.5)*	*(4.5)*	*(3.7)*
Trawlers16-20m	-0.12**	-0.12**	-0.13**	-0.11*	-0.06	-0.05
t-value	*(-2.7)*	*(-2.9)*	*(-3.0)*	*(-2.5)*	*(-1.3)*	*(-0.8)*
Trawlers12-16m	-0.27**	-0.25**	-0.27**	-0.24**	-0.21**	-0.25**
t-value	*(-5.8)*	*(-5.7)*	*(-6.2)*	*(-5.5)*	*(-4.1)*	*(-3.6)*
Trawlers<12m	-0.71**	-0.67**	-0.66**	-0.66**	-0.59**	-0.58**
t-value	*(-10.3)*	*(-10.6)*	*(-10.1)*	*(-9.8)*	*(-7.4)*	*(-5.7)*
Passive >12m	-0.72**	-0.64**	-0.67**	-0.66**	-0.66**	-0.57**
t-value	*(-11.6)*	*(-10.9)*	*(-11.4)*	*(-11.2)*	*(-9.3)*	*(-6.0)*
Passive <12m	-0.78**	-0.8**	-0.81**	-0.78**	-0.68**	-0.64**
t-value	*(-11.3)*	*(-12.6)*	*(-12.8)*	*(-12.2)*	*(-8.9)*	*(-6.2)*

[a] **Significant at a 1% level, *Significant at a 5% level