Potential benefits of biotechnology in aquaculture. The case of growth hormones in french trout farming

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The Case of Growth Hormones in French Trout Farming

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ABSTRACT

Against the background of rapidly increasing fish demand and stagnant or declining marine harvest, aquaculture or fish farming has assumed a major role in France which is set to expand. Trout farming in particular has already displayed considerable growth and France is the leading producer in the EEC.

Biotechnology holds the key to future changes in trout culture. One such technology, which trials show has potential to reduce production costs, is recombinant trout growth hormone (rtGH). This paper sets out to perform a preliminary ex ante assessment of the possible social benefits from the adoption of rtGH by French trout producers. Several scenarios, based on possible hypotheses of supply and demand growth, are considered. Scenarios assuming an association of the technology with diversification towards more highly processed trout products display the highest estimated welfare gains.

A key factor which will determine the outcome of using rtGH is its acceptance by the public. There has already been strong adverse reaction in Europe to the use of genetically engineered growth hormones in meat production and to the use of bovine somatotropin to enhance milk yields. The possibility that there might be a similar response in the case of trout is examined by considering the possibility of a sharp drop in demand.

Part 1 of the paper sets out the economic and technological background to biotechnological development of trout farming in France. Part 2 undertakes an ex ante assessment of potential changes in producer and consumer surplus from the adoption of rtGH applying alternative supply and demand shifts in the framework of partial equilibrium analysis.

1. Background

1-1. ECONOMIC ASPECTS

As indicated in Figure 1, during the nineteen-fifties and sixties the global ocean fishing industry grew rapidly, displaying a threefold increase. This growth was due to a

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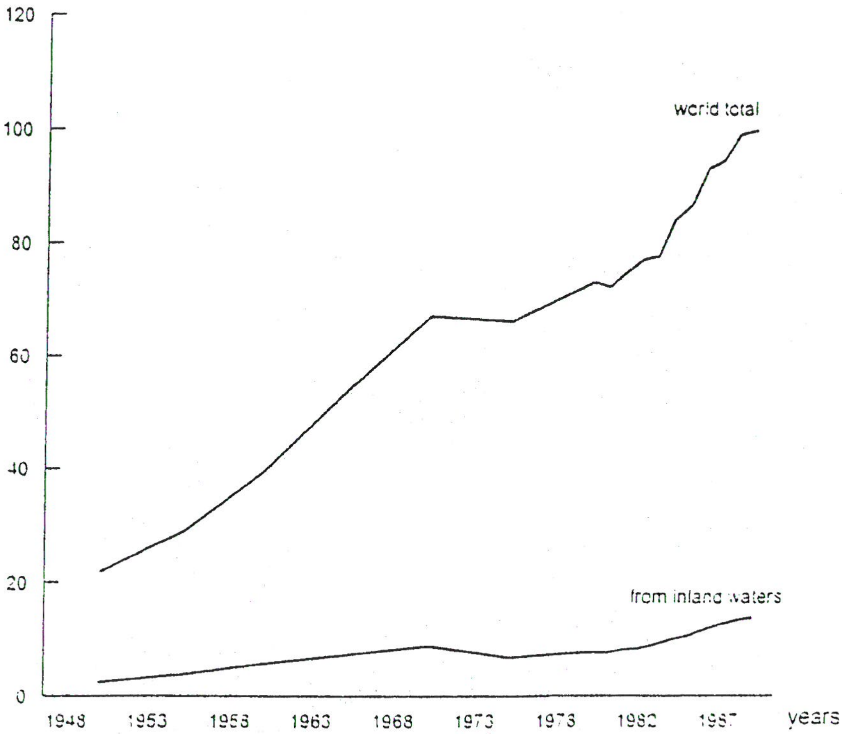

Fig. 1. Fishery commodities: total world catch in million metric tons (aquaculture, mammals, and aquatic plants excluded). ***Sources:*** **FAO, 1991 Fisheries Circular 710; FAO Yearbook Fishery Statistics, Vol. 69, 1989.**

greater commercial exploitation of conventional species with more efficient fishing gears. The building of large fishing fleets capable of operating in distant waters permitted considerable catches of previously unexploited resources. In the nineteen-seventies, there was the depletion of the Peruvian anchovy stocks and total landings reached a plateau. Growth in the world catch resumed to average 3.8% in the 1980s.

Today harvests are tending to decline and total catches in marine fishing areas are unable to attain a level of much more than 85 million metric tons. It is clear that, in the long term, worldwide catches are limited, while at the same time, an upward trend in demand exists, even in developed countries. The recognition of the nutritional and health advantages of a fish diet has intensified the increasing demand for fish brought about by economic growth. Taking this into consideration aquaculture is likely to be the main way to increase the production of fish protein.

In 1984, world output of aquaculture, which includes fish, mollusks, crustaceans, and aquatic plants, was about 4.1 million metric tons and reached 6.6 million metric tons in 1988 [8]. In Western Europe, the aquaculture of salmonids (trout and salmon) is the main activity whereas Central Europe produces more lake fish. Trout farming is predominant in the inland waters of EEC countries with a total of 144,000 metric tons of trout produced in 1989 [9]. This figure can be compared to the 40,000 metric tons of trout produced in the U.S. and the 36,000 metric tons produced in France, the leading European producer.

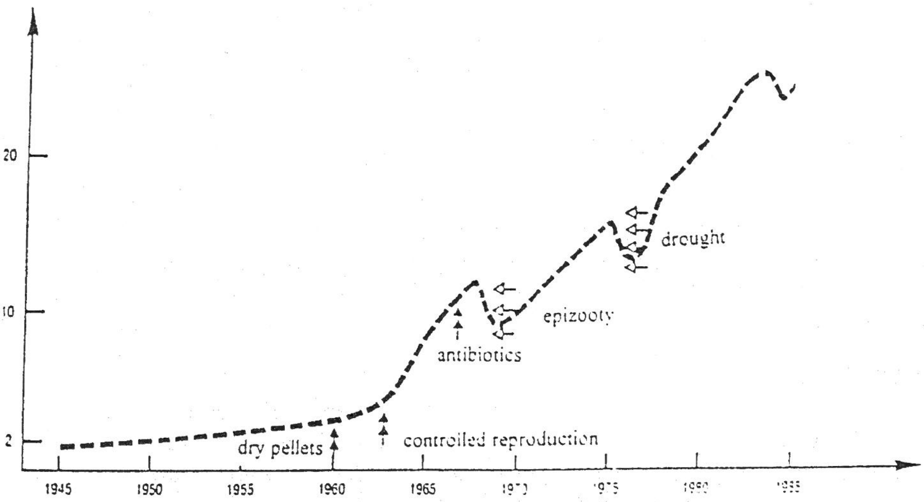

Fig. 2. Changes in trout farming output in France in million metric tons. Source: French fish farming.

French consumption of fishery products is more than twice that of fishery products harvested in France. The French harvesting figure is close to 0.9 million metric tons. Moreover, there is a growing trend in French consumption. During the nineteen-eighties fish consumption per capita increased by 30%. So the development of aquaculture is of a special importance in France in order to meet expanding demands for fish. The recent developments in animal biotechnologies have already revealed the capacity of new biotechnology and growth hormones, in particular, to produce large improvements in meat and milk production, and the potential exists to extend this to fish.

1-2. FISH AND BIOTECHNOLOGY

Beyond the fact that fish aquaculture leads to greater exploitation of water resources, production of fish has several advantages over conventional livestock production: fish produce a large amount of gamets and, in salmonids, fertilization occurs outside of the body cavity, thus leading to the possibility of technological manipulation of eggs. Moreover, as heterotherm vertebrates, fish do not need high energy expenditure for maintaining body temperature and thus have a better food conversion efficiency, compared to other animals.

In France, development of fish aquaculture, mainly involving rainbow trout (*Oncorhynchus mykiss*) imported from North America, appears well adapted for intensive farming. As indicated by Figure 2, development of trout production in France has been very rapid. Several successive improvements of technology explain this change. In the 1960s, use of dry pellets permitted artificial feeding; more recently, development of prophyllaxis and water oxygenation technology maintained a constantly increasing production. However, recent constraints associated with the use of water and impact of fish farming on water quality have led to a plateau in the French production of rainbow trout.

Parallel to the development of fish production, special attention was paid to research with particular emphasis on projects dealing with nutrition, physiology of reproduction, and genetics. This research led to the development of new techniques such as controlling the spawning season by photoperiod manipulation, hormonal synchronization of spawning, production of sterile triploid fish, and production of monosex fish populations. As a consequence trout production is now shifting from a small family structure to industrial structure using high technology.

Several of the above techniques can be classed as belonging to biotechnology, defined as genetic engineering applied either to farm animals or to microorganisms producing recombinant peptides. This last technique, which can produce a large amount of proteins at a lower cost compared to chemical synthesis, has been used successfully to produce recombinant trout growth hormone (rtGH) by several private companies. Use of this recombinant peptide in fish farming has benefitted from much research devoted to endocrine control of growth in fish: these studies have emphasized the potential usefulness of fish rtGH, i.e., a hormonal factor which has very significant biological effects and is a product with flexible uses.

1-3. ZOOTECHNICAL EFFECTS

The main biological effect of rtGH in fish is to stimulate growth. However, recent studies in salmonids indicated that rtGH is also able to stimulate the ability to adapt to seawater. This paper only concentrates on the growth effects of rtGH technology. Alternative positive effects of rtGH supplementation involve (i) a higher efficiency of food conversion thus leading to saving of dietary protein, (ii) reduction of pollution by decreasing nitrogen wastes, and (iii) reduction of fat deposition in the flesh. Negative effects at the liver physiology level have also been reported. Analysis of the literature on the growth response to rtGH treatment in rainbow trout and in coho salmon indicates that it is more efficient when applied to slow growing strains or when rearing conditions are unfavorable (low environmental temperature, for example). Moreover, use of fish recombinant hormone compared to other vertebrate rtGH requires the use of lower doses of hormones. Although these studies have been made using implants or repeated injections, the development of such technology in fish farming will require suitable methods for rtGH application, i.e., oral administration by diet. Digestive tracts in fish have been proven able to absorb macromolecules, thus oral administration of rtGH can stimulate growth in rainbow trout. This method must now be improved by the use of additives which will protect the hormone from the digestive action of the stomach and stimulate intestinal absorption.

Tests, in six different French and European conditions upon trout from 1 gram weight to one month before sale, of continuous rtGH supplementation have been undertaken. In general, it appears that the use of rtGH has negative or no effects on pan-size trout production when applied to farms having a technologically simple system of production. However, a significant positive effect can be demonstrated when rtGH is used in combination with other technologies (for example, oxygenation, controlled photoperiod). In the case of filet production, positive effects of rtGH can be observed in both elementary or high technical situations. Effects of rtGH are still positive although less important for production of large trout. Overall, it seems reasonable to consider the use of rtGH only when trout production is limited by the water resources of the farm. Under such circumstances, chronic hormonal treatment associated with other technologies leads to a substantial increase in trout production in any given situation. This would necessitate important restructuring of the farm and significantly increase the desease risk associated with a permanent functioning of the farm at full capacity. Consequently, only farmers having a high technical ability will obtain benefits from the use of such hormonal supplementation.

Estimation of Social Benefits

Since the mid-1950s, numerous studies have examined the contribution of agricultural research to agricultural productivity. Most studies have been ex post, i.e., they have

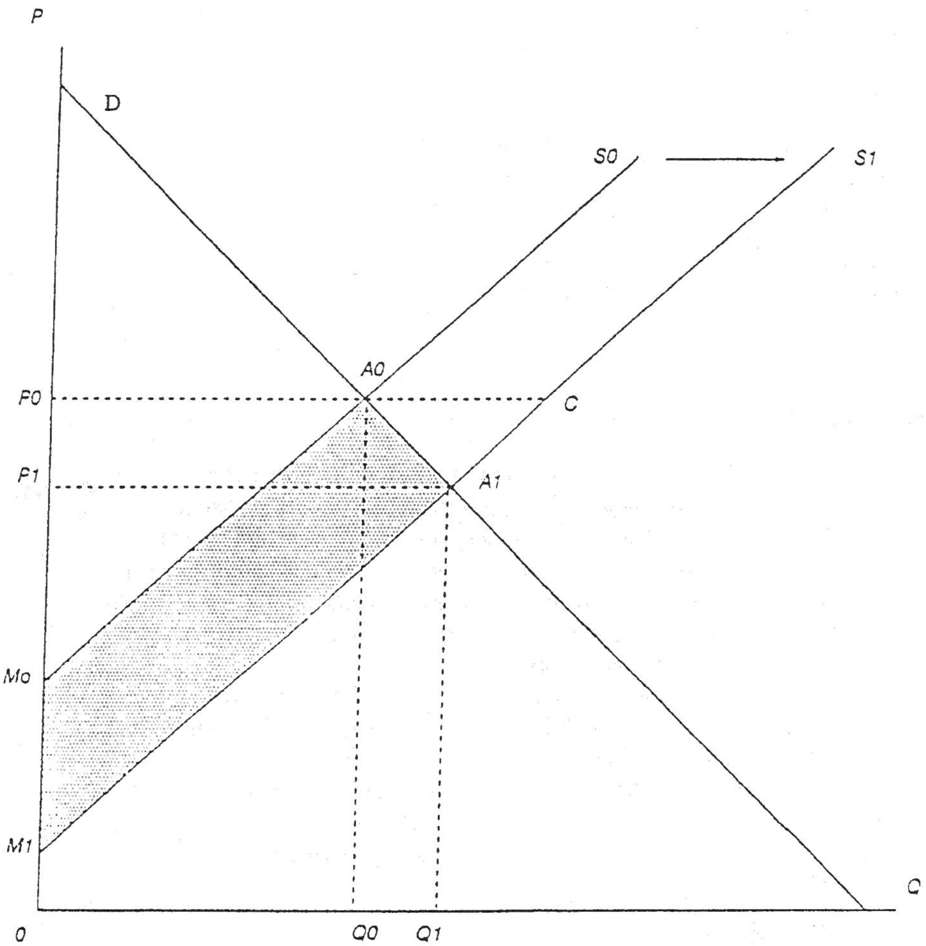

Fig. 3. Benefits from rtGH with a shift in supply.

evaluated completed projects [13]. The current study examines the potential benefits of rtGH in an ex ante framework and follows previous works [14] or [1]. Its results are conditioned by ex ante hypotheses concerning supply and demand shifts over time. So the results are credible as long as the hypotheses are credible from the start. This section presents the following model, briefly describes parameters and data, and summarizes the empirical findings.

2-1. THE MODEL

To estimate the social benefits of rtGH diffusion, the Marshallian concepts of consumer and producer surplus have been used. The basic analytical procedure used in the analyses is illustrated in Figure 3 for the case where there is a shift in the supply curve only.

The original supply curve using the traditional technology is denoted by S_0 and the demand curve by D in Figure 3. The original price is P_0 and the quantity supplied and demanded is Q_0. The supply curve shifts to S_1 following adoption and diffusion of the rtGH, resulting in a new price and quantity of P_1 and Q_1.

Let us consider price elasticity of supply, denoted by E_S and price elasticity of demand, denoted by E_D. The supply shift dS is measured horizontally in the same manner as production increases, therefore dS equals A_0C. Let us denote $P_1 - P_0 = dP$, then the relative change in price is given by:

$$\frac{dP}{P} = -\frac{1}{E_S - E_D}\frac{dS}{Q} < 0 .$$

To estimate the relative change in quantity we move from A_0 to A_1 along curve D. It may be expressed as:

$$\frac{dQ}{Q} = E_D\frac{dP}{P} > 0$$

where $dQ = Q_1 - Q_0$.

Consequently, the supply shift with an unchanged demand implies a drop in price whereas the quantities increase. This means a higher consumer welfare expressed in Figure 3 by the area $A_0P_0P_1A_1$. Concerning the producer surplus, the welfare change resulting from an increase in quantities of goods and a decrease of the price obtained by the producers, is equal to the difference between the triangles $A_1P_1M_1$ and $A_0P_0M_0$. If the supply curve shift is not parallel this difference is not necessarily positive, but the social welfare, as indicated by the shaded area, is positive.

Several formulas have been developed to measure the change in consumer and producer surplus. Differences are caused by alternative specifications for the supply and demand curves (e.g., linear versus constant elasticity) the nature of the supply and demand shifts (e.g., pivotal versus parallel). The various scenarios which are considered below are based on linear specifications and parallel shifts.

It is quite easy to simultaneously consider a shift in the supply curve and in the demand curve [12]. Then:

$$\frac{dP}{p} = \frac{1}{E_S - E_D}\frac{dS - dD}{Q} ,$$

$$\frac{dQ}{Q} = \frac{dD}{Q} + E_D\frac{dP}{P} .$$

A negative shift in the demand curve combined with a positive shift in the supply curve will induce a decrease in price. But the change of quantity can be positive or negative since the relative change of quantity is the addition of two terms with opposite signs.

2-2. PARAMETERS AND DATA

The empirical estimation of the social benefits from rtGH diffusion requires the specification of the price elasticity of trout demand and supply E_D and E_S, and the shift in the trout demand and supply curves dD and dS, and the value of trout price and output, P_0 and Q_0.

No commodity model concerning the French trout industry has been estimated. In fact, such a model would be very difficult to estimate because of the poor quality of available data. Nevertheless, the lack of specific parameters can be mitigated since the question regarding the responsiveness of producers has been researched and is well documented in the literature, making it possible to choose ad hoc parameters. This procedure is a reasonable one since the overall welfare measure is not too influenced by the magnitude of price elasticity. So errors of measurement on this parameter have weak consequences on total welfare change measures, as we shall see. Using French data concerning substitutable commodities like chicken and turkey and data gathered by Askari and Cummings [2], we assumed that short-term price elasticity of trout supply is equal to 1.1. and that long term elasticity is 2.5.

In competitive equilibrium the supply function is equal to the marginal cost function. So the annual shift in the aggregate trout supply depends on the rate of adoption of the rtGH and on the reduction in costs that can be achieved at the farm level. A survey of French trout farmers has shown that only a minority have information on biotechnology in aquaculture [3]. This point has been confirmed by interviews given in Germany, Scotland, and Norway. So in the short run it is expected that the diffusion would be limited, and that it would concern only the largest farms. The general attitude about rtGH is consistent with attitudes of French farmers about the use of bovine somatotropin [4]. Questioned on their opinions, a high proportion of a sample of farmers gives no verdict. But among the dairy farmers, over 60% have a very negative opinion (only 8% thought it was a desirable innovation). However, if bovine somatotropin is authorized, the percentage of livestock farmers envisaging using it is as large as the percentage of those refusing it, i.e., 45% [4]. Moreover, the rate of adoption of bovine somatotropin increases with herd size as seen in California [16] and in Canada [15].

The administration of rtGH induces a positive shift in the frontier of production. In order to estimate the reduction in costs at the farm level, a linear programming model has been used. Three activities were considered (filet, portion, and large trout) and many simulations were run [3]. The utilization of rtGH would increase the profitability of all farm types through a reduction in production cost and an increase in total sales. Moreover, farmers could maintain total profits with a significant decline in price. Finally, rtGH would achieve high relative benefits for cold water fish farms but other farms would maintain their absolute advantage in terms of average costs.

Combining all the above sources, it was possible to set up various assumptions concerning the vertical shift of the aggregate supply. Then, taking into account price elasticity, the horizontal shift could be derived. So a range from 10% in the short run up to 50% in the long run can be expected [3].

Using a time series based on national accounts during the period 1949 to 1988, Combris [6] estimated demand elasticities for 56 types of commodities. Trout is included in a group composed of meat, poultry, and fish with a short-run elasticity ranging from -0.60 to -0.90 depending on the functional form used. For oysters, which is a closely related commodity, Dumont [7] found an elasticity equal to -1.0. For a luxury item such as the Atlantic salmon, the values are -1.97 and -1.83 for the United States and Europe, respectively [10].

For trout, we have considered two values, -0.80 and -1.20, representing a minimum and maximum for the short term. For the long-term elasticity we have taken -1.80. Such a value is meaningful only in cases of change in consumers' preference with a shift in favor of more sophisticated products (processed filet trout).

The demand shift depends on consumer attitudes vis-à-vis trout containing rtGH and more generally towards biotech products. Except for the bovine somatotropin issue, there has been little work on public acceptance of agrobiotechnology. A consumer survey carried out in Germany, France, Italy, and the United Kingdom shows that the consumers' reaction to milk and milk products from biotechnological processes would imply a reduction in demand in all four countries. The percentage of consumers saying they would boycott milk ranged between 17% in Italy to 8% in France [5]. A similar survey made in New York State indicated that milk consumption could decrease by 5.5% to 15.6% if bovine somatotropin was approved [11].

It is clear that food safety questions create a major blockage in the use of growth hormones in livestock production. More particularly, the French example of veal treated with steroid agents is significant. Campaigns carried out by consumer associations in September 1980 against this illegal practice sharply reduced veal consumption. The drop in consumption in the following weeks reached 40%. However, this drop occurred in the context of a downward trend due to the development of industrial veal farming in 1967 and due to an increase in turkey consumption. To sum up, we have considered three basic cases: (i) a small decrease in trout demand with an horizontal shift ranging from −5% to −10%, (ii) a dramatic drop in trout demand with a shift from −40% to −80%, (iii) a small increase with a shift from 5% to 10%.

2-3. SOCIAL BENEFITS ACCORDING TO VARIOUS SCENARIOS

Combining the different values of the parameters we have defined possible scenarios. They can be classified according to four categories.

1. The basic scenarios are those in which the innovation is adopted gradually so the relative horizontal shift of trout supply equals 10% in the short term and then 50% in the long term. Short-term price elasticity of trout supply is assumed to be 1.1. and long-term price elasticity is 2.5. On the demand side there is no shift and the price elasticity varies between −0.8 and −1.2.

2. The most credible scenarios are variants of basic scenarios in which reductions in trout demand are taken into account. Two cases are considered. The first one assumes that there is a slight horizontal shift of trout demand equal to −5% and nothing in the long term. The second one combines a short-term decrease of −10% and a long-term decrease of −5%. So the short term drop is followed by a gradual relative increase. However, this increase is not large enought to offset the initial drop.

3. This category corresponds to the most optimistic expectations. The diffusion of rtGH is very successful since it is accompanied by diversification towards filet trout and large trout, which are more profitable. There is an increase in demand; the relative horizontal shift is 5% in the short term and 10% in the long term. Moreover, trout demand becomes more elastic. In this case price elasticity is supposed to reach −1.8 which is the value observed for salmon demand.

4. These scenarios rely on pessimistic assumptions. There is a more or less widespread rejection of rtGH by consumers corresponding to the situation observed after the campaigns against veal treated with anabolic agents. Here the relative horizontal shift of demand ranges from −40% to −80%. These are short-term scenarios.

Each scenario thus involves specific price and quantity variations remaining within the framework of a static equilibrium approach. Changes in producers' and consumers' surplus were derived for each individual scenario.

Before summarizing the results, we should mention the danger of any mechanistic vision which would lead to erroneous conclusions. This can be understood by considering two extreme cases for the distribution of rtGH and consumer reactions. On the individual farm, the use of rtGH can increase production considerably, which implies a potential growth in the national production which could be of the order of 50% if the innovation becomes very widespread, all other factors being equal. But the "all other factors being equal" qualification is not satisfied due to the interaction between supply and demand. Quantities actually produced will be much lower and in the end, the production increase will be less than 20%. Similarly, a collapse in the demand would be partly offset by lower prices.

TABLE 1
Parameters of Selected Scenarios

	Own-Price Elasticity				Horizontal Shift			
	Short Term		Long Term		Short Term		Long Term	
Scenario	Supply	Demand	Supply	Demand	Supply	Demand	Supply	Demand
1	1.1	−0.8	2.5	−0.8	0.10	0	0.50	0
2	1.1	−0.8	2.5	−0.8	0.10	−0.10	0.50	−0.05
3	1.1	−1.2	2.5	−1.8	0	0.05	0	0.10
4	1.1	−0.8			0.10	−0.40		

TABLE 2
Outcome of Selected Scenarios (in %)

Change in Price		Change in Output		Change in Total Surplus	
Short Term	Long Term	Short Term	Long Term	Short Term	Long Term
−5	−15	4	12	9	26
−11	−17	−2	8	−3	17
2	2	2	6	5	12
−26		−19		−34	

2-4. SOCIAL BENEFITS FOR SELECTED SCENARIOS

Table 1 gives the parameters which define four selected scenarios. Each one illustrates one of the basic categories which have been defined.

The current market equilibrium for France is used as a reference point for the calculations. It is:

Q_0 = 36,000 metric tons, P_0 = 2017 Ecus/kilogram.

Changes in price, output and total surplus are reported in Table 2. Producers' and consumers' surplus variations are displayed (in millions ECU) in Figure 4.

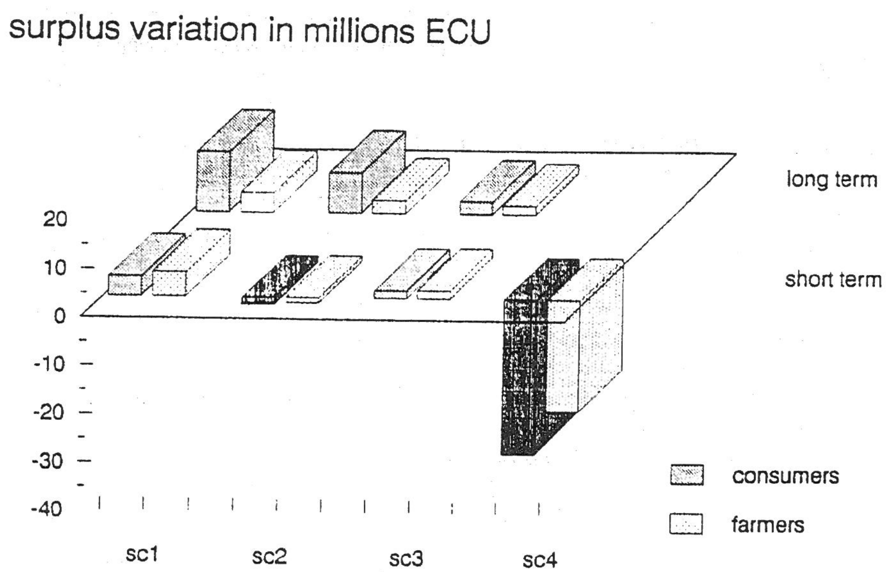

Fig. 4. Impact of rtGH administration: benefits to producers and consumers.

Basic scenarios are illustrated with scenario 1. For constant demand, gradual rtGH distribution scenarios create a significant price drop in the short term (5%), followed by a larger drop in the long term (15%), almost compensated by increased production (4% in the short term, 12% in the long term) which results in stable or slightly reduced revenue in the long term. However, the saving in production costs allows producers to improve their situation with an increased surplus. Consumers would profit from this innovation, therefore it could be considered socially advantageous: total surplus increase equals 9% in the short term and 26% in the long term.

The above results are sensitive to consumer reactions. A slight shift in demand (scenario 2) leads to a larger price drop (11% in the short term, 17% in the long term), a decrease in quantities in the short term (2%), and a limited increase in the long term (8%). Then total surplus decreases in the short term (3%) and increases in the long term (17%). But if the diffusion of rtGH is accompanied by a significant and long-term reduction in demand its social advantage largely decreases. Moreover there are possible scenarios for which total surplus decreases (in the short term and in the long term) which would lead to the conclusion that rtGH is socially disadvantageous.

Scenario 3, which we qualified as optimistic, is based on production diversification towards more highly processed products together with an improved brand image and a long-term increase in the demand. It would create a small increase in prices (2%), in quantities produced (2, then 6%), and in revenue. This would then significantly improve producer and consumer situations. However, diversification would lead to a relative increase in production cost, which would partially compensate for the benefits due to rtGH. The result is a fairly limited increase in the producers' and consumers' surplus. Total surplus increase would equal 5% in the short term and 12% in the long term.

Scenario 4 describes a short-term situation. It is based on the assumption that rtGH will be rejected by consumers. In this case the reduced demand cancels out and overcomes the positive effects of the innovation on the production cost. Price drops of 26% and a quantity reduction of 19% are then possible. This is equivalent to the scenario experienced after the consumers' boycott of veal. It leads to a severe drop in total sales and therefore in producers and consumers surplus: total surplus would decrease by 34%.

Although we may think that the adoption of rtGH would result in social benefits in the long term, shared by producers and consumers, the transient phase is difficult and rejection by consumers would require major restructuring of the industry. A strategy for success would appear to involve diversification and improvements to the brand image. Even so, some effects on the structure of the industry should be expected, and some producers will benefit from the surplus more than others.

3. Conclusions

This paper has drawn on various sources to construct, within a simple partial equilibrium framework, a number of alternative scenarios regarding the possible impact of recombinant growth hormone (rtGH) being adopted in French trout production. Characteristics of what are proposed as the most likely scenarios are (i) for a modest (10%) horizontal shift in the trout supply function in the short run and 50% in the long run, (ii) for price-elastic supply functions, with the long-run elasticity at 2.5 over twice as large as the short-run elasticity of 1.1, and (iii) a modest adverse reaction by consumers to the application of rtGH which causes a modest downward shift in trout demand which declines over time. Assuming that the shifts are parallel it is calculated that both producer and consumer welfare (surplus) would increase, and particularly that of consumers in the long term as much of the benefit of lower production costs feeds into lower prices.

The conclusion, that adoption of rtGH will be socially advantageous in a net sense is speculative at this stage. Under alternative scenarios the estimated benefits could be substantially greater or could be negative in the event that there will be a strong negative reaction by consumers.

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