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# Norwegian salmon aquaculture and sustainability: the relationship between environmental quality and industry growth

by

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## Abstract

This paper discusses the relationship between industry growth and environmental quality in the context of salmon aquaculture. It is argued that industry growth can reduce pollution by inducing more technological innovations for industry-specific pollution-reducing inputs. This increases the elasticity of substitution between conventional factors of production on the one hand, and pollution on the other, and therefore enables a greater degree of internalization of environmental problems. Four indicators of pollution are examined for Norwegian salmon aquaculture. The salmon aquaculture industry is one in which growth is associated with reduced environmental problems not only in relative, but also in absolute terms.

## Introduction

In many cases, industry expansion gives rise to environmental concerns because pollution is thought to be positively correlated with output. However, many economists have supported the view that economic growth can often be beneficial for the environment. At the aggregate level, this view is formulated in the environmental Kuznets curve (EKC) hypothesis, which suggests that some pollutants have an inverse U-shaped relationship with countries' income.[1] In this paper, we look at the relationship between environmental quality and growth at a more

[1] Most of the empirical studies of the EKC are comparative studies on a country level. (See, e.g., Grossman and Krueger, 1995; Shafik and Bandyopadhyay, 1992; Selen and Song, 1994; Panayotou, 1993; Cole et al., 1997.)

disaggregated level, which enables focus on pollution and industry growth. The change in perspective from macroeconomic growth to industry growth can provide new insights into the relationship between growth and pollution. In particular, Lopéz (1994) shows that economic growth can reduce the degradation of natural resources only if producers internalize the effects of stock feedback on production. Sustainable development therefore requires that industries adopt more environmentally-friendly practices and technology as the economy grows, since industries are the major source of many pollutants.

Industries' decision-making in relation to environmental issues is not based on growth in the economy as such, but rather on the industries' own profit maximization objective. In this respect, industry growth is more relevant to environmental practices than to economic growth because industry growth more directly affects the framework within which firms operate. Moreover, one would expect individual firms to respond in a similar way to environmental concerns given that practices are similar for all agents within an industry. This supports the notion that industries represent a natural aggregation level. On the other hand, different industries (or the same industry in different regions) will respond differently to environmental concerns due to heterogeneity between industries (regions), e.g., in terms of the technology and the types of inputs used and governmental legislation. Some will have incentives to internalize environmental problems while others will not. The degree to which producers internalize environmental effects suggests two different measures of environmental improvements, which this paper focuses on: (1) *relative* and (2) *absolute* reductions in environmental degradation. The former indicates that industries have incentives to internalize environmental problems, in which case, the pollution per unit produced (pollution intensity) is reduced. However, a reduction in pollution intensity may not offset the increase in pollution-generating activity (production), and hence the absolute amount of environmental degradation may still increase. Under (2), the industry not only has incentives to internalize, but actually improves its environmental practices to such a degree that pollution decreases, despite increased industry production.

The Norwegian salmon aquaculture industry has been the global market leader since the early 1980s and has also been at the forefront of technological innovation. Annual growth in Norwegian salmon production has been rapid, having averaged 21% between 1984 and 1999 to reach a total output of 464,000 metric tonnes by 1999. The value of Norwegian salmon production increased ten-fold from $0.13 billion to $1.3 billion over the same period (FAO, 2000). Norway is the largest salmon producer in the world, with 46% of the global market in 1999, followed by Chile, the UK, and Canada with market shares of 20%, 14%, and 8%, respectively. Chile, with the fastest growing salmon aquaculture production in the world, began catching up with Norway during the 1990s.

A number of environmental concerns have emerged in the wake of the rapid expansion of salmon aquaculture, many of which can be attributed to the intensive nature of salmon farming. These concerns have ranged from effluence discharges, escaped farmed salmon, diseases and the use of medicines and chemicals, to more global concerns such as the taxation of wild fish stocks, which has been prompted by the large consumption of fish meal and fish oil (Folke, Kautsky, and Troell, 1994; Black et al., 1996; Asche, Guttormsen, and Tveterås, 1999; Asche and Tveterås, 2000; Naylor et al., 2000). The industry has also faced considerable scrutiny from media and interest groups in Norway and from elsewhere because of these concerns. However, most of the indicators of environmental quality show signs of improvement, which suggests that the Norwegian salmon aquaculture industry is addressing these concerns. This suggests that salmon farmers have economic incentives to internalize environmental problems, as has been suggested by Asche et al. (1999).

The paper is organized as follows. The first section presents a theoretical framework for analyzing the relationship between industry growth and environmental quality. The focus is on the conditions for environmental improvement on the one hand, and on the relationship between industry growth and the environment on the other. This section discusses methodological issues relating to empirical testing of the relationship between industry growth and environmental quality. The following section uses the framework outlined in the theoretical section to examine the development of the environmental problems in Norwegian salmon aquaculture. A discussion and summary complete the paper.

## Theoretical Framework

*Conditions for environmental improvement*

Although it is reasonable to suppose that increasing economic activity increases emissions of pollutants, it has been argued that economic growth can reduce the degradation of natural resources if producers internalize their stock feedback effects on production (Lopéz, 1994). Given such a view, it is important to determine the conditions necessary for the internalization of environmental problems, since sustainable development depends on these conditions being satisfied. Broadly speaking, there are two main reasons for a profit-maximizing firm to address the environmental problems that arise from its own activity: either legislation forces the firm to clean up, or it is profitable for the firm to do so. Both imply internalization of the environmental problem since the firm bears the social costs that arise from its own activity. However, policy measures are usually adopted because industries themselves do not have incentives to address these issues. This is usually so in cases where costs are more dispersed, as is the case with $CO_2$ emissions and other airborne pollutants from which there are no feedback effects on productivity (Shafik and Bandyopadhay, 1992). Local pollution tends to be the type that generates negative feedback effects on productivity. Reduced productivity provides firms with incentives to internalize the feedback effects into their decision-making given that they have property rights over the environmental resource. This can be illustrated by using the following profit-maximization problem:

(1) $$\max_{y} \pi = py - c(y) - \mathbf{e}(y)$$

where *py* is income as a function of price, *p*, and the produced quantity, *y*; *c(y)* denotes production costs; and **e**$(y)$ is vector of negative feedback emissions of pollutants as a function of the produced quantity. We assume $c'(y) > 0$ and $\sum_i e_i'(y) \geq 0$ so that increased production increases the cost of production, *c*, and emissions, **e**, if the sum of the feedbacks on cost is positive. Firms are indifferent to the effects of the emissions if $\Sigma e_i' = 0$. Firms have incentives to improve their environmental practices if there are negative feedback effects on productivity, i.e., $\sum_i e_i' > 0$.

Note that in equation (1) emissions are solely a function of output, *y*. In general, this will only be true if the elasticity of substitution between conventional inputs and pollution approaches zero, i.e., in the limiting case of Leontief technology. In more realistic cases, in which the elasticity of substitution is greater than zero, it is possible to reduce pollution by upgrading equipment and technology. This means that the emissions, **e**, can be reformulated as $\mathbf{e}(y, \mathbf{z})$, where *e* is now a function of output, *y*, and a vector of inputs, **z**, with $\mathbf{e}_y > 0$ and $\mathbf{e}_{\mathbf{z}} < 0$. This is a reasonable description of salmon aquaculture, in which an array of different inputs can be used to reduce environmental problems. These inputs include, most importantly, industry-specific inputs such as feeds and feeding technology, vaccines, and medicines.

Increased productivity and reduced costs are not the only reasons why firms may find it profitable to invest in more environmentally-friendly practices. Such investments can also be prompted by consumer behaviour. For example, food-safety issues and the demand for more environmentally-friendly food products have stimulated markets for organic produce. This has influenced decision-making in food industries, since there is a belief that products that are seen to be more environmentally-friendly are priced at a premium and, in some cases, are of a higher quality than conventional products. Studies support the notion that consumers are becoming increasingly concerned with issues relating to food safety and sustainability in relation to seafood production by signalling a willingness to pay a higher price for more environmentally-friendly seafood products (see Wessells and Anderson, 1995; Wessells et al., 1999; Johnston et al., 2001).

*Industry growth and environmental quality*

Before the role of industry growth is discussed, it is important to clarify what is meant by growth in this context. The primary focus of this study is on industries that have reached a size that enables them to capitalize on increased R & D efforts. In this context, the problem with smaller industries is that they lack the capability to undertake the investments required to develop more environmentally-friendly production technologies. An important point is that technology and inputs are often very industry-specific: they cannot be applied in other industries. When large investments are required and there is uncertainty associated with the development of new technologies (or intermediate inputs), potential investors and innovators may be deterred by a small market (industry). In contrast, expanding industries find it easier to attract capital simply due to the implications of growth. For investors, growth represents the prospect of good returns on capital while suppliers see growth providing an expanding market base for their own products and services. Still, it is apparent that the scale of activity must exceed some critical threshold if suppliers and investors are to deem such investments profitable. Moreover, if the industry has incentives to internalize its environmental impacts, then it is most likely that these investments will be channelled towards abatement technologies, and hence increase the elasticity of substitution between conventional factors of production and pollution. This result can be expected whether the internalization is induced by governmental regulations, 'green' markets or by individual property rights, unless internalization signifies some constraint on the industry's output, in which case, unsustainable practices may be causing the industry to contract.

*Measuring the effects of industry growth on environmental degradation*

To test if an industry has incentives to internalize environmental problems, it is useful to formulate an economic model in the form of a cost-minimization or profit-maximization problem. However, because data availability tends to be a restricting factor, it is necessary to consider other ways of modelling this kind of problem. A variation on the EKC model, but at a more disaggregated level, is appropriate given that the effect of growth on environmental quality is of primary interest. In EKC models, the independent variable used to proxy economic growth is usually an income measure, while the dependent variable is an indicator of environmental quality. In this paper, it is industry growth, not economic growth, that is of interest. Industry output can be used to proxy industry growth since it measures an industry's level of activity. This suggests the following relationship:

(2) $$E_{it} = f(Y_{it}) = \alpha + \beta_1 Y_t + \beta_2 Y_t^2,$$

where $E_{it}$ is an environmental indicator (to be defined subsequently). The parameters, $\beta_1$ and $\beta_2$, capture trends in polluting intensity, while $Y_t$ represents the size of the industry and thus also polluting activity. An inverted U-shaped relationship between pollution and industry size corresponds to $\beta_1 > 0$ and $\beta_2 < 0$. This implies that the industry internalizes environmental problems.

We examine two different aspects of this relationship by considering two different measures for the environmental indicator, $E_{it}$, namely *relative* and *absolute* pollution. A relative reduction in pollution corresponds to an inverted U-shaped relationship between the amount of pollution per unit produced and industry growth. A reduction in pollution intensity indicates that the industry has incentives to internalize environmental problems. To a large degree, this dictates whether emerging industries will be environmentally sustainable or not, and is therefore important. However, it is the absolute level of pollution that challenges the resilience of the environment, and therefore this is the most important measure in the long run. An inverted U-shaped relationship between $E_{it}$, indicating the absolute level of pollution, and industry growth implies that environmental quality is improving. In this case, since industry growth corresponds to an increasing degree of internalization, it may be beneficial for environmental quality. This paper uses four pollution indicators (*E*) for salmon aquaculture: the feed conversion rate; antibiotics use; chemicals use; and salmon escapees.

**The environmental concerns of the salmon farming industry**

Consider now the environmental issues in Norwegian salmon aquaculture. Naylor et al. (2000) outline two main groups of environmental problems for the salmon farming industry. The first group relates to the negative effects of salmon farming on the environment, wild fish, and the ecological basis of other living things. These are mainly local and regional concerns. Issues belonging to this group include diseases, medicine use, the impact of organic waste from farms on benthic fauna, eutrophication, the escape of farmed salmon, sea lice, and contamination of the genetic make-up of wild salmon. The second group relates to the pressure put on wild fish stocks by salmon farming's use of large quantities of fishmeal and fish oil in the salmon feeds. This is a global issue. Other global issues include the presence of toxins such as dioxins and PCB in the marine inputs and possible GMO inputs in the feed. This paper examines only local and regional environmental issues. For a discussion of global issues, see Asche and Tveterås (2000).

*Organic waste*

Effluence discharges have been one of the major environmental concerns in salmon farming and account for most of the pollution around fish farms. The organic waste, which comes primarily from fish faeces and waste feed, can build up on the seabed if the rate of decomposition is sufficiently low, and thereby damage the local fauna. Another problem is that the waste leads to higher concentrations of nutrients in the sea, which increase the risk of eutrophication (Folke, et al., 1994). However, Black et al. (1997) point out that eutrophication depends on the nutrients being discharged and on the resilience of the local environment. A strong current increases the availability of oxygen, which is needed for the decomposition of the organic matter, and helps to spread the organic matter over a wider area. Hence, the organic load directly under the cages, and accordingly the challenge to the environmental resilience capacity is reduced. Since seabed topography also influences the resilience of the environment, the siting of cages is important.

However, organic waste sedimentation does not only pose a problem for the local fauna, but also poses a problem for salmon farmers due to negative feedback effects on productivity. The biological decomposition process for the waste reduces the availability of oxygen in the surrounding area and thereby lowers the resistance of the farmed fish to diseases. Moreover, a depletion of the oxygen level in the decomposition process can produce toxic gasses, which, if released, are harmful to farmed fish (Wallace, 1993). Thus, production risk increases with higher feed use because of the negative environmental feedback (Asche and Tveterås, 1999; Tveterås, 1999, 2000). Therefore, risk-averse salmon farmers would minimize feed use and/or take other measures to reduce negative feedback effects on productivity. As feed costs account for over 40% of the total production costs in salmon farming, there is also a cost argument for reducing feed.

Salmon farmers have responded to these problems. First, the feed and feeding technology have improved considerably over the last two decades. Figure 1 shows that the feed conversion ratio (FCR) declined between the 1980s and 1990s. The FCR has fallen from almost three kilos of feed required to produce one kilo of salmon in 1980 to just over one kilo required in 1997. Most of this reduction is due to a greater use of lipids in the feed: a 1% increase in the inclusion rate of lipids leads to a 1% reduction in organic waste. However, new feeding systems have also contributed to reducing the FCR by lowering the feed waste.

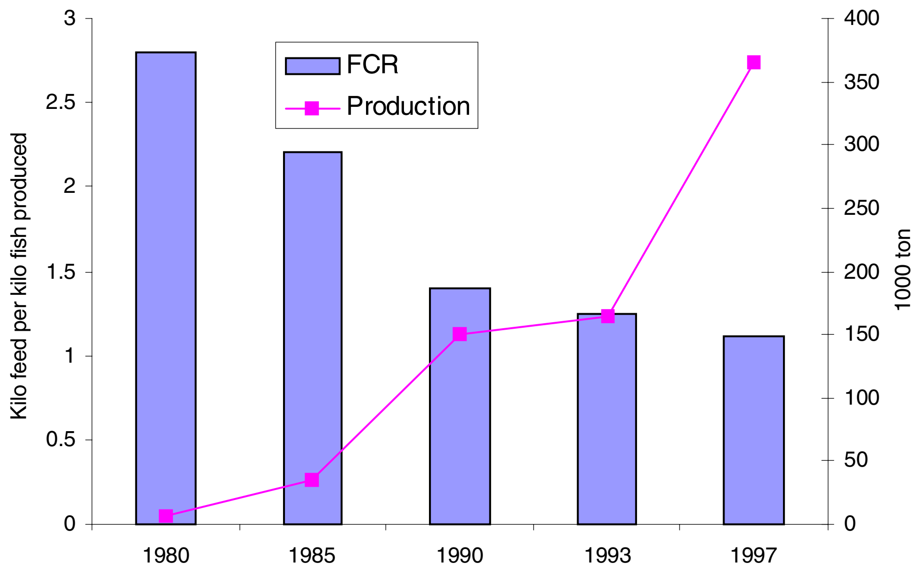


**Figure 1.** Feed conversion rate 1980-1997.
*Source: Directorate of Fisheries*

Second, most salmon farms have moved to areas with stronger currents, deeper waters, and more suitable seabed topography, which significantly reduces the accumulation of waste sediments and negative feedback effects on productivity. In areas with unsustainable locations, salmon farms have disappeared. Thus, the combination of new sea cage technology, which allows sites to be moved to more exposed locations and enables rotation between different sites, and improved feed and feeding technology have significantly increased the elasticity of substitution between traditional factors of production and effluence discharges. This undertaking has probably been promoted by a combination of environmental feedback effects on productivity and a general effort to reduce costs. Consequently, salmon farmers have internalized many of the problems related to organic waste so that the environmental quality of the areas surrounding the salmon farms has improved since the late 1980s.

There is little evidence that the capacity for resilience of the local environment is currently being challenged. Since there is a negative relationship between FCR and output, the reduction in the FCR implies that there has been a decline in relative discharges of organic waste since 1980, implying an inverted U-shaped relationship in relative terms. It is not possible, however, to judge from the available data whether there has been an inverted U-shaped relationship between the absolute level of effluence discharges and the growth of the salmon aquaculture industry in Norway. Calculating the total feed consumption by multiplying the FCR by the salmon production, we find that the total feed consumption has increased, which is not surprising given the explosive growth of salmon farming. This does not necessarily imply that the absolute level of organic waste has increased, however, since there is not a one-to-one relationship between feed consumption and feed waste. If the feed spill percentage has declined substantially, there might be an inverted U-shaped pattern for the absolute level of organic waste relative to industry growth.

In this context it is interesting to note that the improvements in the feed and feeding regimes have to a large degree been made by the feed industry, and not by the salmon farmers themselves. Some improvements in the FCR have been due to on-farm experiments with feeds and feeding systems. However, the feed technology changed in the late 1980s and early 1990s when almost all salmon farmers abandoned wet and moist feeds in favour of dry feeds. Dry feeds are commercially manufactured and therefore not made on-farm. Since then, feed development has mainly been conducted by the feed industry. This indicates that, in the 1990s, the salmon farming industry enjoyed external economies of scale with respect to improved feed and feeding technology.

*Antibiotics and chemicals*

The use of antibiotics in the treatment of diseases is another controversial issue concerning the environmental practices of salmon aquaculture. Antibiotics are controversial since they can lead to antibiotic resistance in fish and other living organisms. In particular, the extensive use of antibiotics in the late 1980s provoked much criticism from consumers. Since then, the use of antibiotics has been virtually eliminated.

Figure 2 shows that the use of antibiotics forms an inverted U-shaped pattern in absolute terms. First, salmon farmers responded to the disease problem in the 1980s by increasing the use of antibiotics. The first large disease outbreaks were the bacterial disease coldwater vibriosis outbreak of 1986 and the 1990-1992 outbreaks of furunculosis. Two factors were important in reversing the trend towards an increasing use of antibiotics. First, the relocation of salmon farms to more suitable locations generally improved fish health. Second, the introduction of an oil-based vaccine in 1992, which was effective against bacterial diseases, made antibiotics more or less redundant. Thus, since peaking in 1987, the use of antibiotics has been on a downward trend, despite a temporary increase in usage following the furunculosis outbreaks in 1990. This contrasts with the upward-sloping trend for production, which is shown in Figure 1. After the first vaccinations had taken effect in 1993, antibiotics were hardly used.

The development of the oil-based vaccine can be seen as the result of the salmon industry becoming an attractive market for industry-specific pharmaceutic services and products. Industry growth therefore made it profitable for the pharmacy industry to invest in the development of such vaccines, which would otherwise not have been available until much later. Thus, industry growth has helped to reduce the use of antibiotics, not only in relative terms, but also in absolute terms.

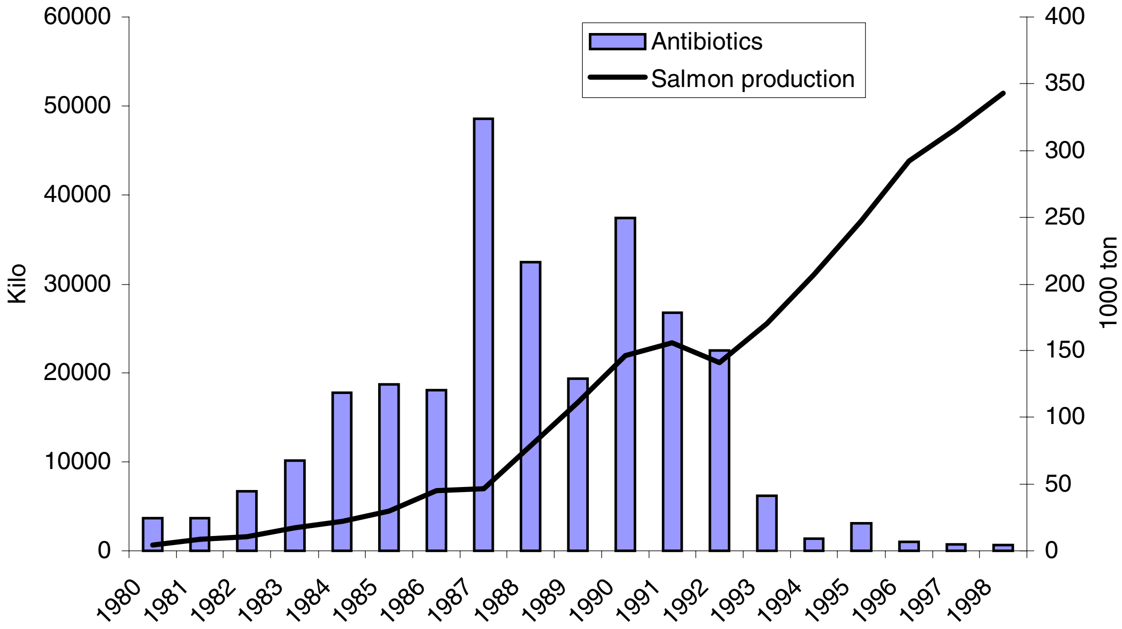


**Figure 2.** Use of antibiotics in the Norwegian salmon farming industry, 1980-1998.
*Source: Directorate of Fisheries*

The same overall trends are found in the use of chemicals. Figure 3 shows that since the mid 1980s, the use of chemicals has been on a downward trend. Because the time-series only dates back to 1984, we only observe the downward-sloping trend in the use of chemicals. However, we can infer an inverted U-shaped pattern for chemicals, given that the use of chemicals must have been close to zero in the 1970s when intensive salmon aquaculture began. Chemicals are mainly used for cleaning cages and for treating salmon lice. Wrasses have been introduced as a more environmentally-friendly method of treating sea lice because they feed on the sea lice that live on the farmed salmon. On its own, this measure is not sufficient to eliminate the sea lice. Hence, although salmon farmers must still rely on chemicals to treat fish that are infected with sea lice, they use considerably less now than they did in the mid 1980s. Yet, as in the case of antibiotics, we observe a lesser use of chemicals as the salmon industry has expanded.

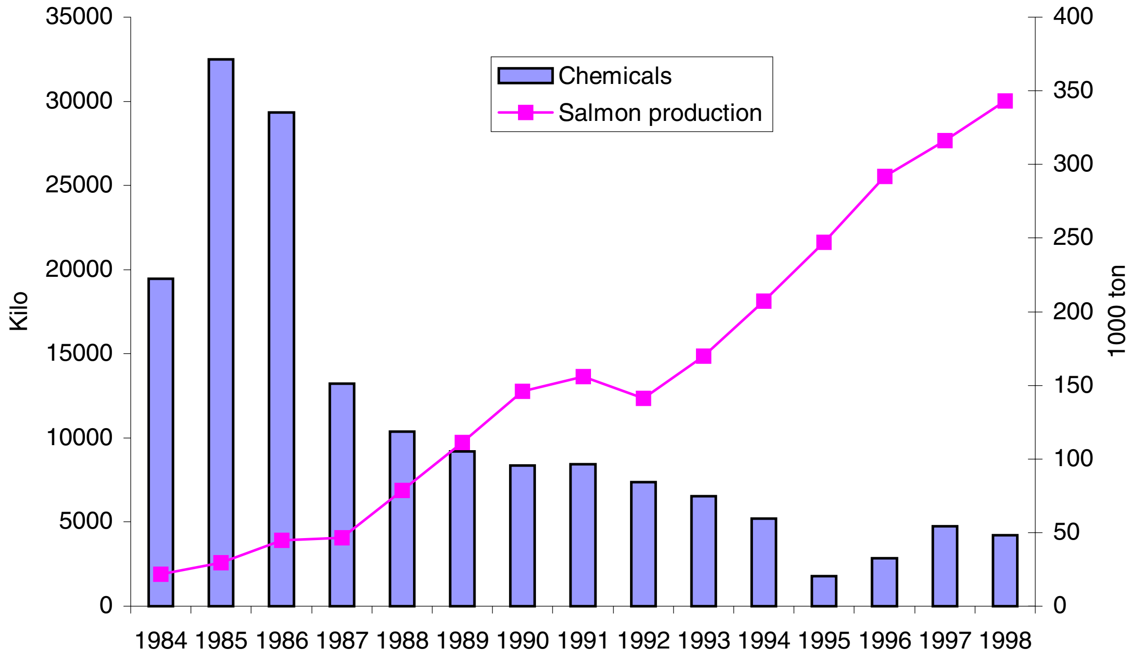


**Figure 3.** Use of chemicals in the Norwegian salmon farming industry, 1984-1998.
*Source: Directorate of Fisheries*

*Salmon escapees and sea lice*

The issue of salmon escapees is controversial because of its potential negative impact on wild salmon stocks. The short-term effects of escaped farmed salmon include competition and breeding with wild salmon, the spreading of diseases and parasites to wild salmon, and hybridization with trout. Since a number of theories have tried to explain why wild salmon stocks have been reduced, the actual effects of farmed salmon on wild salmon are still open to question. Nevertheless, farmed salmon probably have a negative impact on wild salmon stocks.

The main reasons for accidental releases of farmed salmon are winter storms, propeller damage, and wear and tear on equipment. In recent years, better management of these problems has led to a reduced number of salmon escapees, which contrasts with the increased number of salmon produced each year. According to the official statistics presented in Figure 4, salmon escapees have been reduced from between 1.5 and 2 million reported escapees in the 1988-1992 period to about 0.5 million reported escapees in 1999 (The Norwegian Directorate of Fisheries.) This indicates not only a relative improvement, but also an absolute fall in the number of escapees. These figures should be treated with caution because they are probably lower than the actual number of escapees. Since escapes of salmon can generate negative publicity and may even lead to lawsuits, salmon farmers have incentives to under-report the actual number of salmon escapees. Farmers may also be unaware of escapes because damage to cages is detected late, or may not know exactly how many fish are in the cages. However, under-reporting is unlikely to affect the main trends. Thus, it is possible to infer an inverted U-shaped relationship between the absolute number of salmon escapees and the growth of Norwegian salmon aquaculture. This implies that salmon farmers have incentives to internalize this problem.

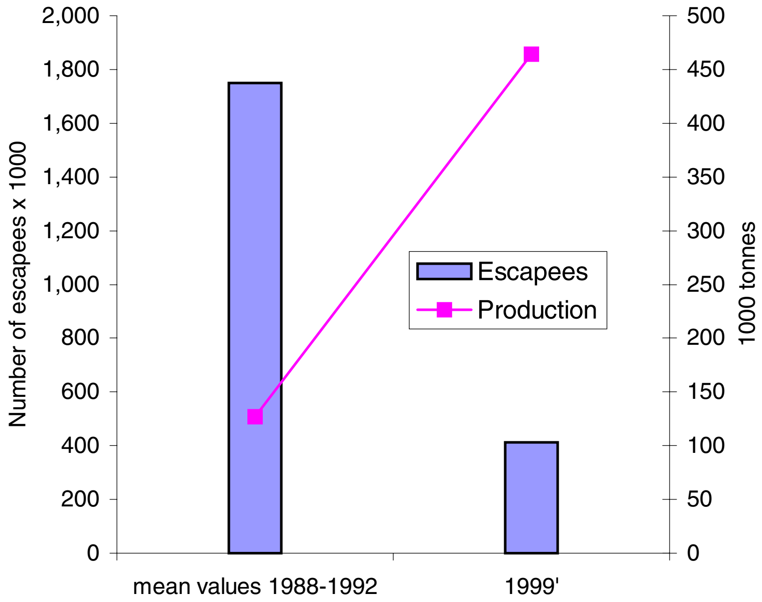


**Figure 4.** Number of escaped salmon in 1988-1992 and in 1999, compared with production.
*Source: Directorate of Fisheries.*

Infection by sea lice is possibly one of the most important factors that reduce the stock of wild salmon. Registrations show that the heaviest infections on wild salmon are limited to areas with a high concentration of salmon farms (Tully et al., 1993a,b; Grimnes et al., 1998). A plausible explanation is that the number of hosts is larger in areas with a high concentration of salmon farms thus leading to a higher concentration of sea lice in that area. Nevertheless, the connection between fish farming and the reduction of wild salmon stocks generates a great deal of insecurity. Analysis of a small sample of rivers in Scotland and Norway showed no marked reduction from 1987 to the present day in farming-intensive areas (Hansen, 1999). However, by comparing 77 different rivers, Sægrov et al. (1997) found that the largest reductions of wild salmon occurred in farming-intensive areas.

Sea lice infections and salmon escapes are probably the major remaining environmental problems in salmon farming today. Salmon farmers clearly have an incentive to limit the number of sea lice because of negative feedback effects on productivity and for marketing purposes. This involves the use of chemicals and sea wrasses. However, it is not clear that salmon farmers have an incentive to reduce the number of sea lice to a level that is significantly below the level required by the market. This means that sea lice concentrations in salmon-farming areas might be relatively high even if the number of sea lice living on the farmed salmon is at an acceptable level. Thus, it is uncertain whether there has been an inverted U-shaped pattern for the level of sea lice in salmon-farming areas. Research on vaccines against sea lice continues, but there has been no breakthrough so far.

**Summary and Discussion**

This paper has investigated the issue of whether some pollutants have an inverted U-shaped relationship to industry growth. Empirical studies of the EKC hypothesis are typically conducted at the macro level and use economic growth, represented by GDP for example, as the explanatory variable to test for an inverted U-shaped relationship for pollutants. However, for many pollutants, there are indications that the industry level is an interesting level to study this relationship at, since industries are the main source of many pollutants. Moreover, industry growth seems to play an important role by changing the framework from which firms operate. Industry growth stimulates more investments, and these investments can be channelled towards the development of abatement technologies and thereby increase the elasticity of substitution between conventional inputs and pollution. This is closely related to the induced innovation hypothesis of Hicks (1932), which says that a change in the relative prices of inputs should induce innovations directed to economizing the use of the input which has become relatively more expensive. Here the relatively more expensive input is pollution provided that industry has incentives to internalize it. An empirical test of this relationship is performed, in which the independent variable is industry growth, rather than economic growth, which is the one used for empirical tests of the EKC hypothesis on a country level. As dependent variables we use the measures of pollution, pollution pr. unit produced and total pollution. This allows us to investigate first, if the industry has incentives to reduce pollution, and secondly, if these are strong enough to lead to an absolute reduction in pollution. Internalization is a pre-condition for industry growth to facilitate the reduction of environmental problems. Therefore, an inverted U-shape pattern of pollution in relation to industry growth will not apply to all environmental problems, since not all industries have incentives to internalize them.

Data from the Norwegian salmon aquaculture industry support the idea that the industry level is an appropriate level at which to study the relationship between changes in environmental quality and growth. The data cover the period from the early 1980s to the end of the 1990s, which was a period of tremendous growth in the Norwegian salmon aquaculture industry. These data provide evidence of inverted U-shaped relationships between environmental indicators and the growth of the Norwegian salmon aquaculture industry. This implies that Norwegian salmon farmers have increased the degree of internalization due to negative feedback effects from pollutants as the industry has expanded. The use of antibiotics and chemicals has been reduced in absolute terms, as may have been the number of salmon escapees. In the case of sea lice and effluence discharges, results are more uncertain given the lack of data. However, the reduction in the FCR shows that, relative to production volume, organic waste discharges have been reduced, which is important given the substantial increase in salmon production over the last two decades.

**References:**


Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., Jansson, B.-O., Levin, S., Mäler, K.-G., Perrings, C. and Pimentel, D. 1995. "Economic Growth, Carrying Capacity, and the Environment". *Science,* 268(28): 520-521.

Asche, F., Guttormsen, A. G. and Tveterås, R. 1999. Environmental Problems, Productivity and Innovations in Norwegian Salmon Aquaculture. *Aquaculture Economics and Management* 3(1): 19-29.

Asche, F. and Tveterås, R. 1999. Modeling Production Risk with a Two-Step Procedure. Journal of Agriculture and Resource Economics 24(2): 424-439.

Asche, F. and Tveterås, S. On the Relationship between Aquaculture and Reduction Fisheries. Paper presented at *IIFET 2000*. Corvallis, Oregon, 10-14 July, 2000.

Barlow, S., 1989. Fishmeal - World outlook to the year 2000. Fish Farmer, October 1989: 40-43.

Black, E., Gowen, R. J., Rosenthal, H., Roth, E., Sechey, D. and Taylor, F.J.R. 1996. The cost of eutrophication from salmon farming: Implications for policy – a comment. *Journal of Environmental Management*, 49: 105-109.

Cole, M. A., Rayner, A. J. and Bates, J. M. 1997. The environmental Kuznets curve: An empirical analysis. *Environment and Development Economics* 2(4): 401-416.

FAO (UN Food and Agricultural Organization) fisheries database. Fishstat+ v 2.30. 2000.

Folke, C., Kautsky, N. and Troell, M. 1994. "The cost of eutrophication from salmon farming: Implications for policy". *Journal of Environmental Management*, 40: 173-182.

Grimnes, A., Finstad, B., Bjørn, P. A., Tovslid, B. M. and Lund, R. 1998. Registration of sea lice on salmon, salmon trout and chars in 1997 (Orig.: Registrering av lakselus på laks, sjøørret og sjørøye i 1997). NINA Oppdragsmelding 525:1-33.

Grossman, M. and Krueger, A. B. 1995. Economic growth and the environment. *Quarterly Journal of Economics*, 112: 353-378.

Hansen, L. P. Status, taxation and stock regulation of salmon. Norwegian Public Report, (*NOU)* 1999:9, Enc. 2.

Hicks, J. R. *The Theory of Wages*. London. McMillan. 1932.

Hilton, F. G. H. and Levinson, A. 1998. Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions. *Journal of Environmental Economics and Management* 35: 126-141.

IFOMA. 2001. International Fishmeal and Oil Manufacturers Association.

Johnston, R. J., Wessells, C. R., Donath, H. and Asche, F. 2001. Measuring Consumer Preferences for Ecolabeled Seafood: An International Comparison. *Journal of Agricultural and Resource Economics*, v26(1):20-39.

Lopéz, R. 1994. "The Environment as a Factor of Production: The Effects of Economic Growth and Trade Liberalization". *Journal of Environmental Economics and Management* 27: 163-184.

McConnell, K. E. 1997. "Income and the demand for environmental quality", Special Issue on Environmental Kuznets Curves, *Environment and Development Economics* 2(4): 383-399.

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C. M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. and Troell, M. 2000. "Effect of aquaculture on world fish supplies". *Nature,* 405(29): 1017-1024.

Nixon, S. W. 1995. "Coastal eutrophication: a definition, social causes, and future concerns". *Ophelia,* 41: 199-219.

NOU. 1999. Til laks åt alle kan ingen gjera? Norsk Offentlig Utredning (Norwegian Public Report) *1999:9.*

Selden, T. M. and Song, D. 1994. Environmental quality and development: Is there a Kuznets curve for air pollution emissions? *Journal of Environmental Economics and Management,* 27:142-162.

Shafik, N. and Bandyopadhyay, S. 1994. Economic growth and environmental quality: Time series and cross-country evidence. *World Bank Policy Research Working Paper* WPS 905.

Sægrov, H., Hellen, B. A., Johnsen, G. H. and Kålås, S. 1997. The development of the salmon stocks in the west-coast of Norway. (Norwegian title: Utvikling i laksebestandane på Vestlandet). LFS-report nr. 34:1-28.

Tully, O., Poole, W. R. and Whelan, K. R. 1993a. Infestation parameters for *Lepeophtheirus salmonis* (Krøyer) (Copepoda: Caligidae) parasitic on sea trout, *Salmo trutta* L., off the west coast of Ireland during 1990 and 1991. Aquacult. Fish. Manage. 24(4): 545-555.

Tully, O., Poole, W. R. and Whelan, K. R. And Merigoux, S. 1993b. Parameters and possible causes of epizootics of *Lepeophtheirus salmonis* (Krøyer) infesting sea trout (*Salmo trutta* L.) off the west coast of Ireland. In Pathogens of wild and farmed fish: sea lice (Boxshall, G. A. and Defaye, D. eds.), pp. 202-213. London: Ellis Horwood.

Tveterås, R. 1999. Production Risk and Productivity Growth: Some Findings for Norwegian Salmon Aquaculture. *Journal of Productivity Analysis* 12(2):161-179.

Tveterås, R. 2000. Flexible Panel Data Models for Risky Production Technologies with an Application to Salmon Aquaculture. *Econometric Reviews* 19(3):367-389.

Wallace, J. 1993. Environmental Considerations. In *Salmon Aquaculture* (Ed. By K. Heen, R. L. Monahan and F. Utter), pp. 127-43. Fishing News Books, Oxford.

Wessells, C. R. and Anderson, J. G. 1995. Consumer Willingness to Pay for Seafood Safety Assurances. *Journal of Consumer Affairs* 29(1): 85-107.

Wessells, C. R., Johnston, R. J. and Holger, D. 1999. Assessing Consumer Preferences for Ecolabeled Seafood: The Influence of Species, Certifier, and Household Attributes. *American Journal of Agricultural Economics* 81(5): 1084-89.