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Adopting a 'High-Tech' Policy in a 'Low-Tech' Industry. The Case of Aquaculture

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Abstract

Low-tech industries, usually defined as industries with a low R&D component, constitute an essential part of the economy in several countries. Providing knowledge on how these industries may sustain economic growth and welfare in the future, therefore represent a key policy issue. In this article a network approach to technical change is applied. The socio-economic trajectory followed by one of the fastest growing low-tech sectors in the Norwegian economy is studied. This path has been shaped by core capabilities in the Norwegian technology infrastructure, and by fundamental changes in governmental policies. It is shown that the increasing competitiveness of the aquaculture industry has gone hand in hand with an increased ability to transform and assimilate very advanced technologies generated within other sectors of the economy. The ability to assimilate such products has been enhanced both by governmental policies and by a dramatic increase in the market concentration ratio within the aquaculture industry.

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1. Introduction

Recent insights and studies into the process of economic growth, triggered by pioneering work by Schumpeter[1], Abramovitz[2] and Solow[3], have put science and technology issues right at the heart of economic policy and industrial competitiveness. Today, few would dispute that a strong relationship exists between technological and economic performance. However, this otherwise healthy consensus has too often led to the oversimplified view that an economy's future ability to generate growth and welfare is predicated on the performance of 'high-tech' sectors[4] such as electronics (ICT generally), biotechnology (and related industries, such as pharmaceuticals etc.). As a result, an overemphasis of the high-tech sectors at the mainstream and research policy levels are created, usually at the expense of low-tech sectors. Both a recent 15-country survey[5] and the budget of EU Third Framework Programme (1990-1994), testify to this situation. In the first, it was found that the majority of governmental R&D support, particularly support of industrial R&D, is channelled into high-tech sectors. The Framework programme reveals that while 40% of the total research budget went into information and telecommunication technologies, agriculture and agro-industrial research including fisheries, received only 5%.

One misconception that has emerged in earnest is that only those countries that command considerable strength in the *creation of high-tech products and services* will be able to compete in the future and thus continue to provide welfare to their populations. Can this be? Today, only a very limited number of countries are in fact able to compete to any meaningful degree in the generation and production of high-technologies. Hopeful competitors meanwhile are generally held at bay by extremely high barriers to entry, entailing high costs and huge markets. The question is: Are small countries, often specialising in low- and medium-tech oriented export markets, thus precluded from generating wealth and general welfare in future?

[1] The late Harvard professor Joseph Schumpeter has powerfully argued through a number of books that the capitalist engine is the introduction of new technologies, or in Schumpeter's words: 'the introduction of new methods of production'. Particularly important work by Schumpeter are: *Theorie der Wirtschaflichen Entvicklung*, 1912, Leipzig, Germany; *Business Cycles*, 1939, New York, USA; *Capitalism, Socialism and Democracy*, 1942, New York, USA;

[2] Investigating the US economy since 1870, Abramovitz found in 1956 that the impact of technical change on the American economy had been substantial: Abramovitz M., 1956, *Resource and output trends in the US since 1870*, American Economic Reveiw, Papers and Proceedings, pp. 5-23.

[3] By investigating the US economy from 1909-1949, Solow showed that only one-eight of the total production increase in the US economy was traceable to the increased capital to man-hour while the remaining seven-eights had to be ascribed to technical change: Solow R., 1957, *Technical Change and the Aggregate Production Function*, Review of Economics and Statistics, Vol 39 No 3, pp. 312-320.

[4] The commonly used definition of 'high-tech', 'low-tech' and 'medium-tech' is the following: Sectors that spend less than 1% of sales on R&D are classified as low-tech, those spending between 1 and 4,5 percent as medium-tech and sectors that spend more than 4,5% are classified as high-tech.

[5] Nelson R.R. (editor), 1993, *National Innovation Systems*, Oxford University Press, Oxford, New York, USA,

The answer must clearly be “No”. It is actually wrong to assume that there is a simple correlation between export specialisation in high tech and general growth. As Van Hulst and Olds’ trans-national analysis[6] showed, no such simple relationship exists. Macro-economic figures do not indicate that the economic performance of small countries was weaker, and empirical tests do not point to any significant relationship between the two indicators of high-tech export specialisation and key indicators of macro economic activity. Another cross national survey revealed similar findings[7].

What people tend not to take into consideration is that most so-called ‘high-tech’ sectors are actually engaged in the production of generic technologies. In practice, they produce capital goods and intermediate goods which flow into other industries. The performance of the economy as a whole therefore depends, not on whether one are specialised in ‘high-tech’ or ‘low-tech’, but rather on how well the industry is able to create *competitive advantages* by successfully accessing, transforming and adopting advanced technologies generated in high-tech sectors. By implication, the most efficient path to competitiveness of a nation therefore seems to be introducing advanced technologies into those sectors in which they already hold a *comparative advantage*[8]. Doing this requires i) a knowledge-based, dynamic policy and ii) major innovative efforts to be undertaken within *all sectors* of the economy.

This paper will analyse variables affecting innovation capabilities in an increasingly important industrial branch in Norway, the aquaculture sector. The focus will be on the impacts of governmental policies. We will follow the transition from what might be labelled a *‘low-tech policy’* to a *‘high-tech policy’*. The analyses is basically a Schumpeterian, or an evolutionary one. This approach, based on induction rather than deduction, suggests that technological choices are *restricted* and *path dependent*[9]. Hence technological performance are *bounded* by historically given core capabilities, former options, governmental policies and the ability to integrate successfully into a wider technological infrastructure, or network, and thereby being able to access and adopt *distant technologies*. From this point of view, technological performance is therefore neither seen as exogenously given (as proposed by neo-classicists) nor as given by R&D intensities[10] only (as assumed within the linear

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[6] Hulst .V. and Olds, B., 1993, *On High Tech Snobbery*, Research Policy 22, 455-62.

[7] Nelson R.R. (editor), 1993, *National Innovation Systems*, Oxford University Press, Oxford, New York, USA.

[8] Hulst .V. and Olds, B., 1993, *On High Tech Snobbery*, Research Policy 22, 455-62.

Hulst V., Mulder R., and Soete L. G., 1991, Exports and technology in manufacturing industry, Weltwirschaftliches archiv, June, 1991

Ergas H. , 1986, Does Technology Policy Matter, Centre for European Policy Studies, Brussels

[9] Nelson R.R. and Winter S. G., 1982, *An Evolutionary Theory of Economic Change*, Harvard University Press, Cambridge, Massachusetts, USA.

Smith K., 1991, *Innovation Policy in an Evolutionary Context*, in Evolutionary Theories of Economic and Technological Change, edited by P.P. Saviotti and J. S. Metcalfe, Harwood Academic Publisher, Chur, Switzerland.

Dosi G., 1982, *Technological Paradigms and Trajectories*, Research policy, nr 11, 147-162, North Holland Publishing Company.

[10] Looking to this indicator of innovative performance only, policy makers may in fact have some reasons for concern: Key sectors in the Norwegian economy including , *fish and fish products*, are characterised by low R&D activity and moreover, these industries spend considerable less on R&D as

model). On the basis of these insights we will trace the path through time and space followed by the aquaculture industry.

a proportion of output than competing industries in other OECD countries. In this study we will, however, show that there are other determinants being equally important for innovative performance.

2. The Rise of the Aquaculture industry, Developments and Policies

2.1. The Historical Dimension

The first known Norwegian initiatives within aquaculture came about in 1855, when customs officer Hetting was employed as inspector of fresh water fisheries. His task was to travel around the country and investigate the conditions and opportunities for artificial fertilising of trout in Norwegian lakes. Subsequently, a number of hatching units for trout and salmon were built. Hetting, together with Dr Rasch, a dedicated professor at the university, experimented further with trout and salmon farming in so-called 'salt water parks'. The idea was to exploit the rapid growth of trout and salmon in salt water, by setting them into enclosures at sea. These experiments resulted in the development of one large salt water park near Larvik in 1875 and another at Sotra in 1877. The project was surrounded by optimism. To general disappointment, the weakly constructed enclosures broke up at sea and the fish disappeared into the open ocean.

During the following decades, several entrepreneurs tried out a number of different concepts but failed. A successful approach to farming salmon in a natural habitat was not found until 1967 when Thor Mowinkel managed to start raising salmon into an enclosed bay. The following year, in co-operation with the large Norwegian firm, Norsk Hydro, he released 70,000 smolt into the sea at Sotra. This success was followed by a breakthrough in floating enclosure technologies in the early 1970's. The new technique was based on freely floating ponds in the sea, meaning that production need no longer be tied strictly to geographical sites such as bay. The benefits of the new techniques started to be reaped, and investment per produced fish fell dramatically. New potentials within aquaculture now became apparent.

Based on the biological and technological breakthroughs on this front, the Norwegian Ministry of Fisheries and the Ministry of Agriculture proposed exploring the potential of artificial hatching, the rearing of fingerlings as well as the rearing of market-sized fish. A proposal was forwarded in 1971, leading to the creation of the so-called 'Lysø-committee' in 1972.

The ball had begun rolling. Through a combination of private entrepreneurship and government incentives, fish production expanded dramatically. From the early 1980's there has been an exponential rise in fish production. Today, Norway is the largest producer of Atlantic Salmon by far, while, in the Norwegian economy , aquaculture has proven one of its fastest growing sectors. Annual production exceeds 200,000 tonnes. *Fish and fish products* represent the third largest export sector in Norway, of which aquaculture is ever more essential. In 1980 the export of farmed fish represented 6% of the total export value of *fish and fish products*. Today this relative share has increased to more than 40%. As a result, approximately 6,000 persons are directly employed in the production of fish in Norway, providing a particularly important source of income for remote regions. What happened, and especially, how did political measures impinge on the sector?

2.2. The Political Dimension

The regional dimension of the aquaculture sector has constantly been stressed by Norwegian politicians. Until recently, essentially two types of objectives have been emphasised by Norwegian regional policy:

- Equality
- Preservation

These two objectives, equal distribution of income and the preservation of traditional settlement, was strongly prominent within aquaculture policies from the early 70's. The 'Lysø committee', mentioned above, saw the establishment of large aquaculture installations as a direct obstacle to these objectives[11]. Accordingly, they proposed setting a ceiling on yearly production per farm[12] emphasising that small-scale aquaculture could be made efficient when co-ordinated with agriculture and fishing. The size of a farm was not allowed to increase beyond one man-year. These ideas were developed further in the Report to the Parliament from 1979[13] at which point a number of restrictions on ownership. Farmers were not allowed to own more than one farm, owners were to be settled in the area of production and individual ownership was to be promoted. It was made clear that profit-seeking speculators were not wanted in this business.

Policies thus set about to establish a sector that might spread and take root in the vast regions of Norway. The regional-political dimension implicit in these policies favoured a labour intensive approach to the industry. This in turn had rather direct implications for the development of relevant technology. It meant that new technologies that could rationalise labour were kept out[14]:

'The conditions offered by Norwegian nature to exploit aquaculture in shielded areas, together with the possibilities of regulating costs within the aquaculture sector are, according to the Ministry of Fisheries, sufficient to establish a competitive aquaculture industry. In order to stay competitive, the Ministry of Fisheries sees no need to rationalise or cut the places of work. Given a level of production, the regional effects are greater, the more workers that are employed. Hence, when designing future plants and plant structures, production should be based on a work intensive concept'

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[11] This is emphasised in Fiskeridepartementet, 1972-73, *Om midlertidig lov om bygging, innredning, etablering og utvidelse av anlegg for klekking av rogn og oppdrett av fisk,* Ot.pr. 46, §2, p.3, Oslo, Norway.Qouting from this paper *"The committee sees the aquaculture sector as a crucial contributor to the general development of remote regions of Norway. From this point of view, the committee sees the development of large units that have the characteristics of industry, as undesirable"* (my translation.)

[12] This proposal was never followed up by formal laws. Instead production were indirectly restricted by putting an upper limit on the *volume* of the ponds. As a result several farmers increased the density of fish and a number of deseases spread quickly within each farm and between farms.

[13] Stortingsmelding nr. 71, 1979-80, Oslo, Norway.

[14] Stortingsmelding nr. 71, 1979-80, Oslo, Norway.

NOU 1992:36, Krisa i lakseoppdretsnæringa, Oslo 1992

In other words, politicians supported a non-innovative climate during this period. The results of the policies are reflected in Fig.(1). In this figure, it becomes clear that labour productivity in fact remained relatively stable for the period, implying a low degree of technical change, innovation and learning.

However, policy makers started to move in a new direction during the mid-80's. It became clear that the implemented policies had not fully taken out the vast potentials inherent in Norwegian aquaculture. Capital was difficult to attract to the sector. Several farmers and investors put their money into foreign countries were laws and restrictions (imposed on the aquaculture sector) were less rigid. Adding to the problem, was the fact that throughout the 80's farms where hunted by several severe diseases. This showed that aquaculture indeed was a risky business. This was especially so in Norway, where risks could not be spread on several farms due to ownership regulations. As a result investments in aquaculture were reaching a suboptimal state and so did also the potential creation of a number of places of work. Simultaneously, the international prospective of aquaculture was clearly revealed due to the decrease of the wild fish stock. Farmed fish represented an interesting substitute.

As a result the policy makers implemented a 'high-tech policy' within a 'low-tech' industry. The policy implications of making the aquaculture industry internationally competitive can be seen in 'Odelstings proposisjon' 53, 1984-85, which stressed the need for regulations to become more flexible. The Report to the Parliament from 1986[15] followed up on this line by stressing the importance of developing a profitable and competitive industry.

This vote of confidence, as it were, led to aquaculture being launched as a key industry in several regions in Norway. R&D figures from the period reflect the extent of change. From 1984 to 1989 the public R&D expenditures rose by approximately 300%. Meanwhile ownership regulations were gradually liberalised. The requirement for localised ownership/management of farms was dismantled in 1984/85[16]. This attracted new capital to the sector, although major investment opportunities were narrowed due to a law that restricted the number of farms that one person could own. This restriction was softened in 1991 and hence opening up for the possibility of market concentration. Single owners or firms were given permission to own more than one farm, though a clause remained giving the department authority to restrict owner concentration in special cases[17]. Simultaneously, the maximum permitted farm sizes were allowed to increase, from 3000 cubic metres in 1981, 5000 cubic metres in 1983, 8000 cubic metres in 1985 and 12000 cubic metres in 1988.

In sum three major policy incentives gathered momentum from the mid 1980's:

- A substantial rise in governmental R&D
- Liberalisation on ownership
- Increase of permitted farm sizes

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[15] Stortingsmelding nr 65, 1986-87, *Om havbruk*, Oslo, Norway.

[16] Ot.prop.nr.53 (1984-85)

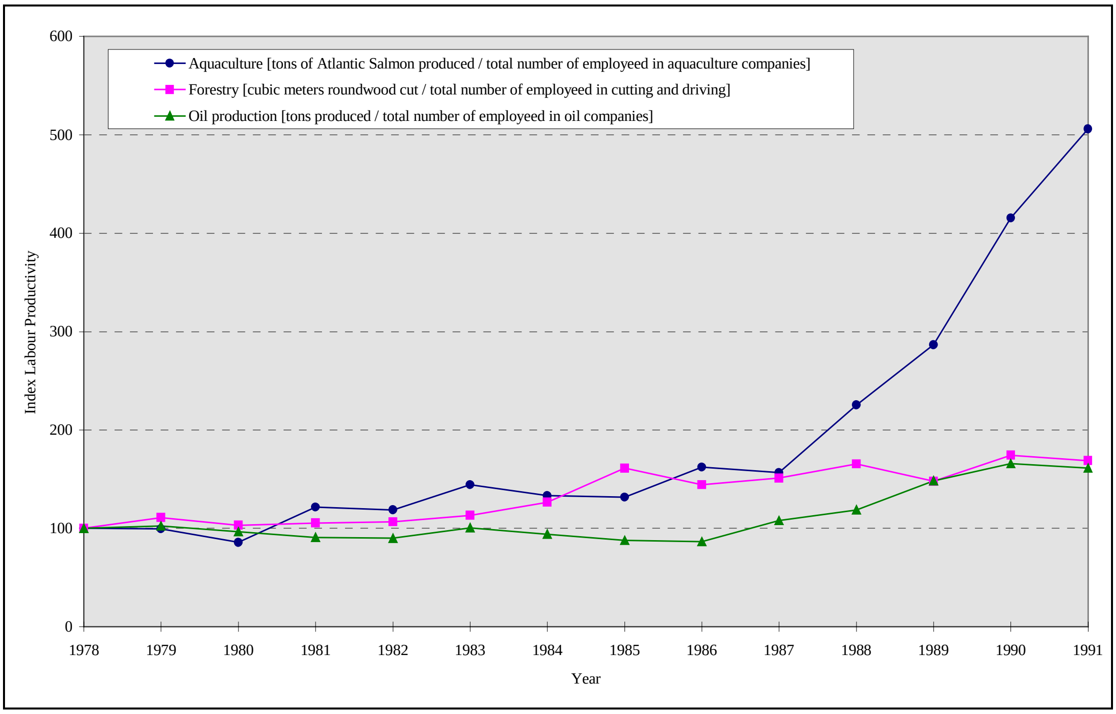
[17] Fiskeridepartementet, 1990-91, *Om lov om endring i lov 14. juni 1985 nr 68 om oppdrett av fisk, skalldyr m.v.*, ot.prop.55, Oslo, Norway.

What were actually the impacts of these radical changes imposed on the industry? These questions will be explored in the following sections.

3. Impacts of the Policy Transition

It may be argued that , during its development phase of 70s to the mid 80s, the aquaculture industry had been suspended in a state of equilibrium by highly restrictive policies that surpressed learning potentials, scale economies and the subsequent adoption of advanced technologies. In this period , fairly equal players, both in size and competence made up the market. Capital and competence were difficult to attract and both capabilities and incentives to innovate were very poor. Interviews conducted inside the industry during the period indicated that technologies were seen as being simple and easy to imitate. Technical change moved only very slowly and incrementally. The industry was in a stage of very nearly perfect competition, moving within an equilibrium state where the needed time for an innovation to emerge largely exceeded the time it would take that technology to be diffused and imitated. In other words there were hardly any barriers to entry, no economies of scale and information spread reasonably perfectly. The situation thus resemble the theoretical conditions upon which neo-classical economics usually build: Firms had relatively unproblematic access to all available technologies and could switch between technological choices rapidly and with little costs[18].

Figure 1: A comparison of labour productivity growth in aquaculture, forestry and oil production from 1978 - 1991. Labour productivity is set at 100 for all three industries in 1978[19].



[18] PREST, MERIT, NR, 1993, Technology and the Transition to Environmental Stability, Maastricht, The Netherlands

[19] Statistisk sentralbyrå, Oslo, Norway.

After the emergence of the new policies, the situation changed dramatically. From this point, the position of technology begins to defy the assumptions of the neo-classical model, recommending it for an evolutionary framework. Technical change started to gather momentum and imitation time lags where exceeding innovation times. A first indication of the development is seen when looking to labour productivity data. Hand in hand with the changed competitive environment in aquaculture, labour productivity has increased dramatically. Between 1987-1991 labour productivity increased by a factor 3.3, Fig.(1). By way of comparison, the fastest growing industrial sector in the period 1924-1950 had an increase in output per operative of 272%[20]; placed against newer figures from industries like *oil* and *forestry*, the productivity increases in aquaculture compare favourably as well (cf. Fig.(1)). We follow up this discussion in the sections to come, getting a deeper understanding of the development and its causes.

3.1. Market Structures and Technical Change

The new emerging policies in the mid 80's, resulted in a substantial increase in the production capacity per farm. Measured in tons the average production was more than doubled from 1986 to 1990. In 1982 approximately 40% of the farms produced between 0-50 tons of fish for consumption, while in 1990 only 0,7% of the farms produced between 0-50 tons. What are the impacts of this production increase? In this section we explore the concept of learning curves that dynamically relates output quantities to innovative capabilities and technical change.

The learning curve effect is a pragmatic observation which has been systematically seen in a number of industries throughout the world: Production costs of a particular item tend to sink as a function of time and practice. This effect was first observed in 1925 in the Wright-Patterson Air Force base in Ohio[21]. The assembling of aircrafts showed the following pattern: The fourth plane required only 80% as much direct labour as the second, the eighth plane, only 80% as much as the fourth and so on. Thus the rate of learning to assemble aircraft was concluded to be 80% between doubled quantities. This implies that learning increases rapidly in the production of the first units, and eventually falls off with volume. This is illustrated mathematically by Eq.(1)

$$Learning\,[output\ per\, man-hour] = C_1 \quad V^{-C_2} \tag{1}$$

or inverting Eq.(1)

$$Productivity\,[man-hour\ per\, output] = \frac{1}{C_1}V^{C_2} = CV^{C_2} \tag{2}$$

V is *accumulated volume.* C_1 and C_2 are constants, where C_1 is determined by initial conditions and C_2 is determined by the learning rate within the specific industry. C_2 takes a value between 0 and 1 and hence productivity change has the characteristics, $dp/dv > 0$ and $d/dv(dp/dv) < 0$.

[20] Reinert E., 1980, *International Trade and the Economic Mechanism of Underdevelopment*, Ann Arbor, University Microfilms International, Michigan, USA.

[21] Hirschman, W. B., 1964, *Profit from the Learnig Curve*, Harvard Business Reveiw, USA.

As a result of different levels of complexity in different industries, learning does of course vary. Theories about these mechanisms can be traced all the way back to 1776, when Adam Smith wrote 'The Wealth of Nations'. Smith argued that with a larger output of some product, variable cost coefficients would decrease due to *the division of labour*. Smith gave three reasons for this decrease in cost[22]: i) workers can specialise more and build up a greater proficiency in their work, ii) time is commonly lost when passing from one type of work to another, iii) the invention of machines that facilitate and reduce labour will raise output per worker[23].

More generally, learning curves may be interpreted in two ways, either in a *static* or a *dynamic way*. According to the static interpretation, increased productivity results from instantaneous rises in productivity when scaling up. If output contracts and the company scales down, these productivity gains are immediately lost. The gains in productivity are thus reversible. The dynamic interpretation, on the other hand, entails an irreversible process. Learning-by-using and learning-by-doing are important factors in this category. These factors are usually ascribed to the rate of growth in output where the gains result from 'learning' more efficient methods of production and are as such not lost even when the company scales down. *An essential observation is that a rapid expansion of production eventually leads to (as a well as being a result of) a greater rate of innovation and a climate more favourable to risk taking*[24].

This fact is closely related to variables influencing innovation like the cost of *capital* and *competence*. Employing competent, well-educated people is usually quite costly. These costs must generally be spread over a larger output. Spreading the salary of for instance the manager over a larger output volume, opens the possibility of paying higher salaries which presumably will attract managers of superior ability. The relative cost of a supervisor or highly educated people will determine, in the long run, the company's incentive to hire well educated people. The increasing outputs of aquaculture firms hence open for rising competence levels as the cost of attracting and retaining this expensive human factor can gradually be spread over larger output. This can lead to a virtuous circle of development, whereby higher general education levels in the fishery industry are stimulated thus raising innovative performance and competitiveness of the fishery industry in general[25]. Traditionally low competence in this specific industry has in fact constituted a substantial problem. Studies from the early 80's reveal that while the share of white collar workers in Norwegian industry in general was 27%, this share was only 10% within the fishery sector[26]. Less than 40% of the employees holding leading positions had completed secondary school, less than 10% have formal education from business schools or technical schools lasting more than one year.

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[22] Scherer, F.M. and Ross, D, 1990, *Industrial Market Structures and Economic Performance*, third edition, Houghton Mifflin Company, New York, USA.

[23] One negative effect of the division of labour is the problem that arises when workers are too spezialized and consquently are unable to adapt creatively to new situations and technical change in general. The trend has been away from such specialization where creative adaption is important.

[24] Mc Combie J.S.L., *Verdoorn's Law*, Palgrave Dictionary

[25] Kommunaldepartementet, 1990-91, *På rett kjøl, om kystens utviklingsmuligheter*, Stortingsmelding nr. 32,Oslo, Norway.

[26] Fiskerinæringens landsforening, 1994, Norsk fiskeindustri mot år 2000, Troms trykk AS, Tromsø, Norway.

In addition to raising its competence recruiting power, the aquaculture industry can further expect to reap benefits from increasing production on capital markets. A study of the cost of debt in the 60's revealed that corporations with assets of $5 million borrowed at an average interest rate of 0.74 percentage points higher than firms with assets of $200 million while billion dollar corporations enjoyed a 0.34 point incremental advantage over these[27]. Investors demand higher returns from the securities of small corporations as compared to larger ones owing to expectations of risk: Statistical studies indicate that profitability varies less over time for large individual companies than for smaller companies[28]. Thus some of the traditionally large problems in the fishing sector, related to low capital accumulation, may be overcome by exploiting scale economies in capital borrowing. Generally among several industrial sectors, lack of capital access, especially in the periphery, is seen as a major obstacle to innovation[29].

The important fact to emphasise is that the general phenomenon of learning curves is very relevant in studying the aquaculture industry, which exhibits special rates and quality of learning. Fig.(2) demonstrates that the enormous production increase from the mid 80's is associated with a substantial labour productivity increase. When imposing the '80% inverse learning curve' on the inverse learning curve in aquaculture, Fig.(2), it is seen that the Norwegian aquaculture industry had a relatively slow start compared to the standard 80% pattern of learning. Throughout the 80's the fish farm learning curve approaches the 80% standard curve. In the early 90's, however, it actually takes off from that curve.

The fluctuations of the aquaculture learning curve relative to the general 80% learning curve may be seen not only against the background of the increased production of farmed fish, but also on the background of the increased market concentration ratios that emerged during the period. The four-firm market concentration index CR4, rose from less than 5%[30] in 1990 to nearly 25% in 1993. In the early period of the industry, the market concentration ratio was even less than 5%. Thus the accumulated volume of output per farm, relative to the total output, was very low during the 70's. According to the premise of this section, low accumulated volumes result in low experience per farm and therefore a poor innovative climate, slowing progress down the cost-output curve. In the 90's the market concentration ratio increased rapidly, pushing up the accumulated volume per farm increased, and with it the rate of innovation, while pressing on down the cost output curve.

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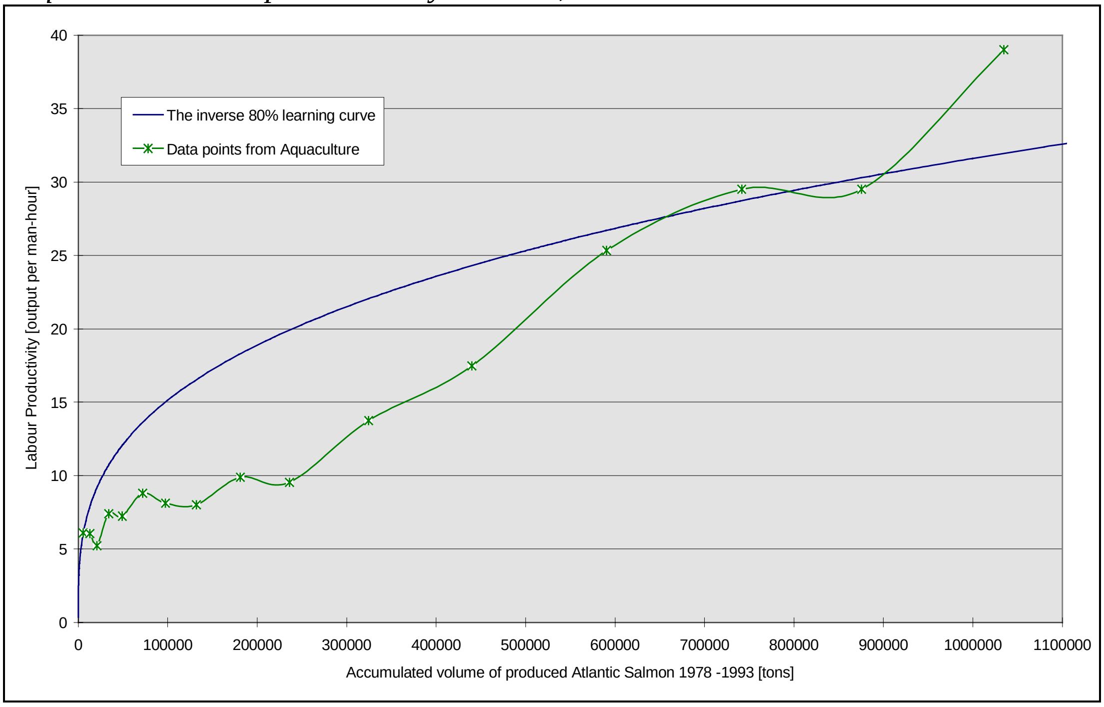
[27] Scherer, F.M. and Ross, D, 1990, *Industrial Market Structures and Economic Performance*, third edition, Houghton Mifflin Company, New York, USA.

[28] Scherer, F.M. and Ross, D, 1990, *Industrial Market Structures and Economic Performance*, third edition, Houghton Mifflin Company, New York, USA.

[29] Nam, Ch. W. et al., 1990, *An empirical assessment of factors shaping regional competetivness in problem regions*, Commision of the European Commmunities, Luxembourg.

[30] Based on number s from Fiskerinæring nr 7, 1990 and Fiskerinæring nr 7, 1991 and sector statistics from SSB.

Figure 2 : The inverse 80% learning curve, Eq.(5.3), and the spline interpolating the labour productivity data within aquaculture31, 1978 - 1993. The first datapoint for aquaculture corresponds to the year 1978, the second to the 1979 etc.32



There are several implications of the existence of learning curves. I will review some of those related to public policy below[33]: Learning curves or experience curves are not only related to the increase in labour productivity. In general, learning curves are related to the decrease of costs when the accumulated produced volume of a company increases. One possible implication of this is that that antitrust policies lead to higher costs for each company and to a lower degree of technical change in general (due to narrowing learning opportunities). The Boston Group estimated that if all production of one product is concentrated in one producer instead of spread equally among 8 producers, the costs would be 35% to 50% that of the average costs of these 8 producers. This is especially interesting when looking at aquaculture, a highly export-oriented industry. Companies with the highest degree of experience, or those with the highest production volumes, have from the above theories the lowest costs[34].

If the expansion of Norwegian firms is limited by governmental regulations, while foreign firms are not, foreign firms may run down the cost-volume curve faster than competing Norwegian firms, thus reducing costs faster than Norwegian firms. If foreign firms decide to trade current profits for future markets and lower prices, Norwegian firms may be trapped. In this situation, a gap between the cost-structures

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[31] Calculations based on data from SSB and norske fiskeoppdretteres forening, 1993.

[32] Usually the learning curve is designed on the basis of one company. The datapoints for aquaculture is however, based on summarised numbers for all companies in Norway. The initial conditions are though set to the same value for both curves in Fig 2. This allow us to compare the dynamic development of the two curves.

[33] Boston Consulting Group, 1968, *Perspectives on Experience*, Boston, USA.

[34] This hypothesis, based on data from Norwegian firms, will be quantified in the next section.

of large unregulated foreign firms and those of Norwegian ones would quickly open, squeezing the latter firms out of the international market. Following the argument in this section, to overcome such a gap would mean letting Norwegian firms again increase production volumes and exposing them to a painful and lengthy process of selling below costs. However, this path seems neither desirable in terms of its economic consequences nor permissible in terms international dumping regulations. It should be noted that claims of dumping have been lodged against Norwegian firms before by the EU countries and the US and that these threatened to put the aquaculture cluster in Norway out of business[35]. Therefore, regulation of the industry, especially with regard to the size of enterprise unit, should clearly be kept in mind both due to the importance of the Norwegian aquaculture industry for regional employment and its reliance on establishing and maintaining international competitiveness.

What is then the ‘correct size’ of a fish farm? First we must explore technological change within the sector, a variable which surely affects the ‘correct size’ of fish farms.

3.2. The Role of Aquaculture within the Norwegian Knowledge Infrastructure

In parallel with the changed market conditions and the rapid learning taking place within the aquaculture industry, its ability to develop networks with science and supplier enterprises has increased. We explore the absorptive capacity and the technological opportunities of the industry in this section.

According to evolutionary theories, the ability to produce new economic growth in an industry largely depends on its potential to regenerate its technological bases and/or the extent to dynamic technological opportunities exist in an industry. In this light, the question then becomes: what types of changes in technologies are undertaken within the industry, where are the major areas of technological advance and the main “knowledge bases” which support and co-operate with the industry[36].In exploring these issues for the aquaculture case, three central aspects are interesting:

- firstly , the specific activities which are involved in aquaculture
- secondly, the types of techniques which are used, and
- thirdly, an overview of the kinds of knowledge bases which underlie those techniques

A general overview is provided in the following table:

[35] Blakstad, Frode og Dahle, Lars Andre: *Utvikling av norsk utsyrsindustri til havbruksnæringen. Perspektivanalyse 1992 - 2010.* Marintek AS og Akvainstituttet AS, Tronheim 1994.
Salvanes K.G. and Tveterås R., 1992, Stabilisering av varemarknader: Ein analyse av innfrysningsordninga for laks, vedlegg 3 i Krisa i Lakseoppdretttsnæringa, NOU 1992: 36, Seksjon statens trykking, Oslo, Norway.

[36] Dietrichs, E. and Smith K, 1994, *Hva er fiskeriteknologi - en oversikt over fiskerienes teknologiske grunnlag og dens regionale dimensjon*, Step rapport 22/94, Oslo, Norway.

Table 1: Activities, technologies and scientific knowledge bases in Norwegian aquaculture. Research institutes committed to the different activities are also indicated.37

Activity	***Technology***	***Research Knowledge Bases***
Construction of Ponds, moorings, cranes, lifting-equipment boats	materials technology, wave analysis, hydrodynamics , surface technology, construction- and welding technology, Information technology, CAD, CAM,	Simrad Subsea AS, Sintef Norsk hydroteknisk laboratorium, Marintek, Havforskningsinstituttet, Fiskeriforskning
Monitoring	Sonars, information technology, computerimaging, electronincs, advanced mathematical algorithms, acoustics, optics	Simrad, Lindem, Sintef
Health, laboratory services, vaccines, chemicals	nutrition technology, bio technology, electromicroscopy, gas technology, thermodynamics, marine biology, chemistry hydrodynamics	Norges Veterinnærhøgskole, Norconserv, Akvaforsk NLVF, Fiskeridirektoratets ernæringsinst., Inst. for næringsmiddelhygiene-NVH , Inst. for bioteknologi Sintef Norsk hydroteknisk lab., Havforsknings inst., Inst. for fiskeri-og marinbiologi, NINA, Fiskeriforskning, Vetrinærinst., Norbio AS, Inst. for fiskeri-og marinbiologi, Inst. for akvakultur NVH, Fellesavdeling for farmakologi og toksokologi NVH, Inst. for medisinsk biologi UNIT, Inst. for mikrob. og plantefysiologi UIB, Teknisk kjemi Sintef, Biologisk inst. UIO
Feed	process control, industrial processes, chemistry, marine biology, hydrodynamics, extrusion technology, monitoring technologies, information technology, nutrition technology	Akvaforsk NLVF, Fiskeridirektoratets ernæringsinst., Inst. for bioteknologi Sintef, Sintef Norsk hydroteknisk laboratorium, Havforsknings-instituttet, Sildeolje- og sildemelindustriens Forskningsinst., Fiskeriforskning, Fiskeridirektoratets ernæringsinst, Marintek AS, Norges Fiskerihøgskole
Feeding Machines	materials technology, information technology, telecommunication, electronics, cybernetics high pressured air technologies, robotics, welding technology	Fiskeriforskning, Akvaforsk NVL Ås

[37] This table is based on information from *NFFR's prosjektkataloger 1986-1993*, *Norsk Fiskeoppdrett*, *Havbruk* and intervjues and visits at different plants.

Table 1 (Continued)

Measurements and manipulation of colour and fat	nutrition technologies, biotechnology, spectro photometer, bio physics, computer tomograghy, NIT, NIR, NMR spechtrography, 3D measurements, visions and camera technology, marin biology	Norsconserv, Fiskeriforskning, Akvaforsk, institutt for bioteknologi Sintef
Measurements and manupilation of stress before slaughtering	high pressured liquids, chromography, magnetic resonance, biophysics, marin biology	Teknisk kjemi Sintef, Fiskeriforskning, Havforskningsinstituttet
Slaughtering, filleting	mechanical industry, mechanics, information technology, acoustics, optics	Fiskeriforskning
Sorting, counting and weighing of fish	mechanical industry, information technology, electronics, laser technology, mathematical algorithms, optics	Fiskeriforskning, Havforskningsinstituttet
Fish processing, refine ment	mechanical industry, freezing technology, information technology, programmable logical systems, robotics, optics, acoustics	Fiskeriforskning, Havforskningsinstituttet
Conservation, cold storage	materials technology, refrigeration technology, gas technology, NMR spectroscopy, thermodynamics, transport theory, biology, electronics	Institutt for bioteknologi NTH, Institutt for kuldeteknikk NTH, Fiskeriforskning
Trading of fish	information technology, telecommunication, signal processing, electronics	Marintek, NORUT Fiskeriforskning
Transport and transport equipment	material technology, mechanical industry, welding technology, refrigeration technology, gas technology, telecommunication, signal processing, thermodynamics	Marintek

Tab.(1) demonstrates a close linkage between the principal technologies of the Norwegian aquaculture sector and some of today's most advanced areas of industrial innovation[38]. The salient observation is that aquaculture, typically classified as a 'low technology' sector according to the standard OECD definition, in fact is an industry in which advanced technologies are created, transformed, adopted and used. As Tab.(1) essentially illustrates, aquaculture is the subject of substantial spillovers from other industries.

An example of such spillovers comes from the food sector industry. A technology known as extrusion that originated from the plastic foil industry, revolutionised aquaculture industry in the early 80s. Extrusion, basically a thermic process that converts solids into manipulatable, soft plastic mass, was applied to fish feed. In this application, the organic feed, having been converted into a plastic mass is run

[38] This pattern of technology use is not reflected in the internal R&D of the industry itself, and the usual indicator of technology intensity (the R&D/Sales ratio) is a very unsuitable indicator of the real technological characteristics of the industry.

through a dicer and made into pellets, which are then dried. The change-over to dry feed , also forced change in complementary technologies, notably mechanical feeders. In the early 70's wet-food, unrefined bi-products from commercial fisheries were dominant in aquaculture. Transport costs were high as this type of feed had to be pumped through expensive acid proof pipes from land to the farm-enclosures. *Dry feed* dramatically lowered transport as well as maintenance costs. The feed was both lighter and could be conveyed and dispersed by means of air and not water pumps, amongst other things reducing wear and tear on the pumps and pipes. As a result, a large cluster of complementary technologies has emerged which also involve technologies from the plastic industry: today's wet-feed machines are approximately 3 times more expensive than the dry-feed systems.

Both feed-systems rely however on the bi-products of commercial fishing, particularly 'junk fish.' As pressure on the oceans' fish stocks increase, with more and more 'junk fish' supplementing exhausted high quality sorts, [39], aquaculture's feed base is becoming more uncertain. This prospect has led to the industry's search for new sources for feed. Here again, aquaculture sector seems to be able to take advantage of technologies originally generated elsewhere. The oil industry is developing an artificial single cell *protein* by feeding bacteria methane gas. *Biomar*, a feed company owned by the oil giant *Norsk Hydro*, finds the technique promising for the use in farm feeds.

Another important area of technological spillover connected to feed techniques is monitoring technology. In this area, interesting technologies are being developed which promise to help farms in the important job of ensuring effective feeding regimes. To this end, the aquaculture industry is in the process of adopting and adapting the sonar technology that has become a mainstay of more traditional fisheries in gathering information about the exact location and volume of fish stocks . Such techniques, based on high-tech information technologies, acoustics and advanced mathematical algorithms, can be used to monitor the behaviour of the salmon in their pens. Monitoring behaviour in this way over time can help establish feeding patterns. Further, as farm managers learn to recognise behavioural patterns, this technique might also be used to uncover early symptoms of spreading diseases.

It is important to note that the Norwegian firms involved in developing monitoring devices tailored to the needs of the aquaculture sector were also those active in developing sonar for traditional fisheries, attesting to an active spillover process. Other areas in which Norwegian firms are advancing are sea-farm enclosure technologies, sea vessels and general offshore equipment. A report about European competitiveness[40] indicates that Norway's strong industrial cluster related to shipping industry, offshore and sub-sea technologies have put it in the lead in Europe.

Norwegian aquaculture is building its way into this cluster, learning from it while contributing to it. In fact the labour productivity in aquaculture and that in oil industry are correlated by a factor $r = 0,93$ in the period from 1978 - 1991. Tab.(1) demonstrates that several of the research institutions active in aquaculture also have

[39] The Economist, *The tragedy of the oceans*, March 1994.

[40] T. Reve and Mathisen L., 1994, *European Competitivness*, Norges Handelshøyskole, Bergen, Norway.

substantial interest in the oil industry. *Sintef* pops up repeatedly in this table, especially under the name *Marintek* which is a strong research resource in general offshore technologies. Particularly active in cross-industrial links are supply-oriented firms such as Trio Machines, Aga Gass, SM Remote Systems, Fina Exploration, BP Norway, BP Nutrition, Hydrogas and Marinaqua (Hydro/Statoil) which are involved both with aquaculture and the oil industry. Meanwhile the Norwegian oil giant, Norsk Hydro, owns one of the biggest fish farms (Mowi AS) and food producers (Biomar) in Norway.

Tab.(1) however suggests that innovative capabilities related to fish-processing are poorly developed within the Norwegian knowledge infrastructure. On this front, Norwegian enterprises lag behind German, Danish and Icelandic firms, against whom they have some trouble establishing themselves. The tactics of the dominant players, who e.g. use service contracts that bar other firms (i.e. Norwegians)from conducting repairs on their equipment, prevent potential Norwegian firms from valuable *learning by doing* experience.

Having trouble competing head to head with established firms who are far ahead on the learning curve, some Norwegian firms are managing to establish themselves in this industry through other channels. The dominant firms rely to a large degree on their established expertise in ‘mechatronics’, a hybrid of mechanical engineering and electronics applied to fish-processing. Some Norwegian firms have found that they can get involved in advances on this front through joint-ventures or in becoming suppliers in international clusters. One case of this phenomenon is the case of Norwegian *Trio Machines*’ co-operation with the German giant *Baader*. A further instructive example involves fish weighing equipment sold in Norway. Here the hardware component is provided by the Icelandic firm *Marel*, while the software is supplied by *Maritech Systems*.

As shown above, Norway is, in such high tech sectors as acoustics, optics, electronics and information technologies, building up considerable knowledge resources and applying them to aquaculture and fisheries. The Marel-Maritech case illustrates that this approach may be the way ahead for Norway in the fish processing field as well.

Norwegian aquaculture is in the technological forefront within several fields. Crucial in this development have been the already existing Norwegian clusters within shipping, offshore, and traditional fishing technologies. A knowledge infrastructure depending on these milieus has been successfully established very much due to the new market conditions with large competitive firms being able to absorb distant technologies by establishing links to very advanced scientific milieus. Within this infrastructure an innovative and technically very advanced aquaculture industry has grown up. An essential point about low-tech industries is hence revealed through our analyses: i) these industries do not necessarily create or access new technologies via internal R&D, and ii) they often use inputs that are highly advanced and R&D intensive.

3.3. Technical Change and Minimum Efficient Size

The rapid technological change mapped above have affected the 'Minimum Efficient Size'[41] in the aquaculture industry. In this section, we explore this issue by looking to scale elasticities in terms of the following model:

First, let's choose a scale elasticity, $\varepsilon(y)$, in such a way that constant returns to scale give $\varepsilon(y)$=1; increasing returns to scale give $\varepsilon(y) > 1$ and decreasing returns to scale give $\varepsilon(y) < 1$. Eq.(3)[42] satisfies these restrictions:

$$\varepsilon(y) = 1 / \frac{\partial \ln f}{\partial \ln y} \qquad (3)$$

where f is the minimal costs required to produce a quantity, y.

On the basis of Eq.(3) and data from the Department of Fisheries on costs and profits from different Norwegian farms, Salvanes[43] has estimated the scale elasticity, $\varepsilon(y)$, within Norwegian aquaculture companies in the period from 1982-90. The results are shown in Tab.(2).

Table 2: Scale elasticity, $\varepsilon(y)$, for the average firm in Norwegian aquaculture 1982-90. The null hypothesis is constant returns to scale, i.e. $\varepsilon(y)$ = 1.

Year	**1982**	**1983**	**1986**	**1987**	**1988**	**1989**	**1990**
$\varepsilon(y)$	1.0360	1.0455	1.3327	1.3665	1.1764	1.1418	1.1696
Stand. error	0.03421	0.0215	0.0270	0.0351	0.0135	0.0100	0.0143
t-value	1.06	3.18	11.95	10.44	13.07	14.18	11.86

Tab.(2) demonstrates that there were increasing returns to scale from 1983-1990. During the same period the size of firms increased. From 1986 to 1990 there was a radical increase in the average production per farm. Measured in tons, the average production per farm more than doubled from 1986 to 1990. In 1982 approximately 40% of the farms produced between 0-50 tons of fish for consumption, while in 1990 only 0,7% of the farms produced between 0-50 tons[44]. Hence it can be concluded from the data that, while farms are increasing in size, it is possible to continue to increase sizes further and thus pursue lower unit costs for the average sized firm.

The same authors found that even for the largest farms in Norway, scale potentials were not fully realised in terms of scale elasticity for different levels of production within a year (i.e. the local characteristics of the scale elasticity) Companies

[41] MES denotes the smallest size a plant may be in order to attain minimum costs.

[42] Salvanes K. G. and Tveterås R., 1992, *Kostnadsutvikling for norsk oppdrett 1982-90: Intertemporale og regionale produktivitets skilnader*, pp 156-171, Vedlegg 3 til Krisa i lakseoppdrettsnæringa;

Christensen L.R., Jorgenson D.W., and Lau L.J., 1973, *Transendental Logaritmic Production Frontiers, Reveiw of Economics and Staticstics* 55, pp 28-45.

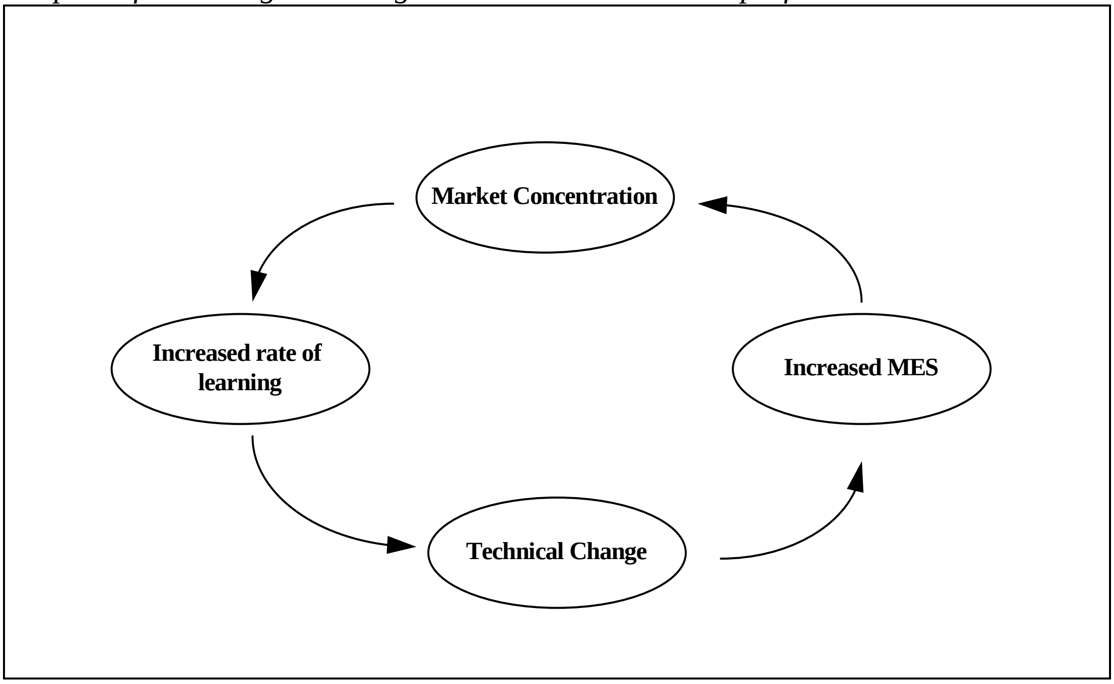
[43] Salvanes K. G. and Tveterås R., 1992, *Kostnadsutvikling for norsk oppdrett 1982-90: Intertemporale og regionale produktivitets skilnader*, p. 165, Vedlegg 3 til Krisa i lakseoppdrettsnæringa.

[44] Fiskeridirektoratet

producing 600 tons per year still had a scale elasticity of *1,11* in 1990 while similar study in 1989[45] showed that the scale elasticity was approximately *1* for the largest firms in 1982-83. That meant that, at that time, economies of scale were fully exploited and further expansion would not increase profits. Despite the fact that today's largest farms are larger than those in 1982-83, they demonstrate a scale elasticity higher than *1*. This indicates that- the minimum efficient size, MES, is on the increase.

The increasing MES may be understood by looking at the technological development within the industry. Interviews showed that the technological methods and level in aquaculture before 1985 advanced according to 'trial-and-error'. The farmers generally drafted the pens themselves, while engineering firms were contracted to construct them . These enclosures were often unable to withstand the elements and the weak equipment of a good deal of farms were torn apart in storms. These would be repaired and improved and launched time and again.

Figure 3: A cascade effect of technical change in a process oriented industry. The impact of technological change on MES and innovative performance is shown.



In general, a pattern of the 'home made' characterised the early fish farms. It was not until the mid 80's, that aquaculture's increasingly apparent potential lured in a number of equipment suppliers and research institutions. With them, science entered the industry in the form of sophisticated lab facilities. This spurred a period of technological advance (e.g. submarines, sophisticated monitoring equipment, advanced feeding systems, large boats: see above) and concomitantly, increasing returns to scale. In turn, this development has apparently served to increase the MES, a general tendency that is recognisable from several other process industries[46].

[45] Salvanes K. G., 1989, *The structure of the Norwegian aquaculture industry: An empirical analysis of Economies of scale and substitution possibilities*, Marine resource economics, 6: 349-373.

[46] See examples in Scherer, F.M. and Ross, D, 1990, *Industrial Market Structures and Economic Performance*, third edition, Houghton Mifflin Company, New York, USA

We have found that technical change has impacted on the MES of fish farms. The growth of fish farms has further spurred innovative capabilities and learning within the industry. Market concentration, technological change and MES is hence interrelated properties as illustrated in Fig.(3). All these variables are highly policy relevant. The government may hence create a competitive environment spurring learning and innovative capabilities and thereby enhancing the absorptive ability of firms to draw on the capabilities within a well funded *technological infrastructure*[47]. Furthermore, by looking to Fig.(3), one sees that by regulating plant sizes, not allowing plants to expand to MES, the process of learning and technical change may slow down. On the other hand, it is quite clear that increasing farm sizes beyond certain limits may have serious environmental impacts. We turn to this issue in the next section.

3.4. Scale, Ownership and Environmental Impacts

The above arguments show some of the benefits to be achieved by increasing plant size. Nevertheless, companies cannot lower unit costs by increasing output indefinitely. At a certain point diminishing returns to scale will arise. Some of the factors limiting the profits of increasing outputs beyond a certain level involve the following[48]: Learning curves flatten out at very large cumulative outputs, creative adoption by workers may be lost at a certain level of division of labour, communication paths becomes inefficient beyond a certain plant size, motivation of workers declines at a certain plant size, machines require special structural reinforcement beyond a certain size, advantages of mass reversals flatten out at a certain output level, transportation costs per unit increase at a certain output level. Lastly, in the case of accidents, environmental damages increase sharply with plant size. In the following we will especially focus on this latter aspect.

Are there plausible operational structures taking into account environmental issues and that also are capable of exploiting economies of scale? Or in other words, how may policy makers optimise the competitiveness of the farms also taking into account environmental restrictions? We will in the following explore the environmental impact of ownership regulations imposed by policy makers.

Fish farmers which want to exploit economies of scale, basically face two different choices.

i) The farms are expanded to MES, all farms have separate owners.
ii) One farmer buy several other farms, or a number of companies starts operating together as a merger; (the size of the farms staying unchanged)

Reinert, E., 1992, *Industripolitikk og ulandsproblematikk - to sider av samme sak?* Fremtek notat 22/92, Oslo, Norway.

[47] For an excellent review on the concept of *technological infrastructure policy* see M. Justman and M. Teubal, 1995, *Technological infrastructure policy: creating capabilities and building markets*, Research Policy 24, pp 259-281.

[48] Scherer, F.M. and Ross, D, 1990, *Industrial Market Structures and Economic Performance*, third edition, Houghton Mifflin Company, New York, USA

Let us look at these two possibilities in more detail: Due to the strong ownership regulations, option i) was actually the only plausible one until 1991[49]. From an environmental point of view this kind of ownership regulations, where several farmers each run separate plants, is highly negative. There are two reasons for this:

First the MES of each farm in *option i* is larger than the MES of each farm in *option ii* (due to more complicated communication and transportation paths). Larger farms contaminate fjords more than smaller ones, this is the case both in the routine operation of the farm and in case of accidents. Still, although each pond is smaller within *option ii* (than within *option i*), several of the benefits related to large scale are maintained. Learning-by-doing and learning by using may in fact be even larger in a multi-plant company than one operating a single farm, although the single-plant operating company might control a huge farm. Firstly, the multi-plant operating firm may draw experience from a number of different locations. Secondly, a company that runs several farms is likely to produce a higher volume of fish than a single farm and therefore is able to run faster down the learning curve than its single farm competitors. Furthermore, the high output from the multi-farm company implies high capital assets, which, as argued in Sec.(5.1). entails scale benefits when borrowing capital. Overhead and competence may show similar patterns in the case of large single-farms if they too are also spread over similarly large production outputs. Mergers are perhaps especially interesting in the case of small firms joining large ones. As argued in Sec.(5.1), capital raising enjoys especially pervasive large economies of scale. When a small firm joins a large one, the smaller firm is likely to benefit from the larger enterprise’s lower cost of capital. Indeed for small firms without ready access to outside capital markets, difficult borrowing conditions may be ameliorated. Case studies reveal that this may be one of the most compelling advantages of mergers[50]. In addition, the small firm gets access to the knowledge, competence and market base of the bigger firm and vice versa.

The second environmental related argument might be illustrated by the following case: Imagine a fjord consisting of 10 farms, both the population of salmon in each farm and the size of each farm is equal. Assume that the contamination from all the farms is spread equally around the fjord. For simplicity we define environmental damages as measured by the number of dead salmon only. Suppose one farm, Company A, contaminates at a certain level, let’s say an amount equivalent to the death of N salmons within a time period of n years. Within n years all farms will lose $N/10$ salmons due to the contamination done by company A. Hence company A only bears 10% of the direct costs due to the its own environmental damages. Suppose now that company A buys all 10 farms in the fjord, while the biomass remains unchanged. Now contaminating the fjord, company A has to bear 100% of the costs due to the damages it has caused to nature. Thus a company’s incentive to contaminate is lower, the larger volume of the sea the company has cultivated. Hence reducing the number of firms operating within one region (the biomass being

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[49] Adding to the problem was also the production regulation during the period. The upper limit on production where put on pond volumes, not on production quantities. Consequently several farmers wanting to exploit economies of scale, increased the density of fish in the ponds. In turn, increasing the density of fish, stressed the fish and made it less resistant to deseases.

[50] Scherer F.M. and Ravenschaft D. J., 1985, *Mergers, Sell-offs and Economic Efficiency*, pp 212-213, Washington Brookings, USA.

constant) is likely also to reduce contamination. Thus *option ii*, which only have been plausible from 1991, is much more in line with environmental issues. Hence, (from the above arguments), increasing market concentration ratios, increases incentives not to contaminate.

The actual development within Norwegian aquaculture in fact underlines this latter point. During the period when ownership was restricted on a one-owner, one farm basis, a series of severe diseases struck Norwegian aquaculture[51]. In 1976 the first serious disease hit an enterprise in Hammerfest and gradually spread down the coast. This was followed by another epidemic, 'Yersiniose', that left large numbers of dead fish in its wake, all along the Norwegian coast, from Finmark to Hordaland. A bacterial kidney disease, 'BKD', hit plants in Hordaland and Sogn og Fjordane. Infectious salmon anemia, 'ILA', broke out and spread along the coast the following years. 'Furunucleosis', 'Vibrose' and followed by a number of other diseases that spread along large parts of the Norwegian coast. The aquaculture industry reacted to these diseases by heavily medicating their salmon by putting antibiotics into the fish food. In 1987 the total amount of antibiotics utilised in aquaculture well exceeded the level utilised in human medicine. While 49 tons active substance of antibiotics were utilised in aquaculture, only 25 tons were utilised in human medicine and 12 tons in veterinary medicine in Norway.

Hand in hand with the deregulation and liberation on ownership and the following market concentration, environmental issues became highly apparent. Effective vaccines were developed within an interdisciplinary milieu involving both scientific knowledge centres and the aquaculture industry. In train with these common efforts the volume of antibiotics declined dramatically. From 1987 to 1992 the amount of antibiotics being utilised sunk from 49 tons to 25 tons, and in 1993 to 6 tons[52]. In 1994 the volume approached zero. Associated with this development, some of the largest aquaculture companies have recently done substantial research on 'Green salmon' or 'Environmental salmon'. Central to this work is the aim to reduce the plants' extensive use of chemicals. The outcome of this process was the introduction of a fish called 'gold sinny wrasse', which feeds on the salmon's sea lice. Many of the largest farms in Norway are now substituting previous reliance on extensive chemical delicing solutions by introducing gold sinny wrasse into the pens. In addition to removing sea lice from the salmon, the gold sinny wrasse also eat organisms growing and accumulating on the ponds, for instance mussels. Therefore the farmers may also reduce the number of surface treatments as lamination of the ponds etc. Most such lamination entails copper which is poisonous to the environment. Norwegian aquaculture utilises approximately 800.000 litres of lamination per year which contain about 130 tons copper. Approximately one gram of copper is today utilised per farmed fish. Hence the potential environmental gains in utilising gold sinny wrasse are substantial. The incentive to introduce knowledge-

[51] Adding to the problem was also the production regulation during the period. The upper limit on production where put on pond volumes, not on production quantities. Consequently several farmers wanting to exploit economies of scale, increased the density of fish in the ponds. In turn, increasing the density of fish, stressed the fish and made it less resistant to deseases.

[52] NENT, 1993, Oppdrettslaks - en studie i norsk teknologiutvikling, TMV forlag, Oslo, Norway.

Norske fiskeoppdretters forening, årsberetning og regnskap 1993 intensive, environmentally friendly products hence seems to be dependant on ownership structures.

It is pointed out that there are increasing returns to scale in aquaculture. In order to exploit this element of the economy under environmental restrictions, the most plausible future competitive structure within aquaculture seems to be mergers or companies operating several plants within the same region. This structure enjoys several of the same benefits as larger, single-plant companies do, and in addition the solution is ‘greener’. Governments should encourage structures of multi-plant operations or mergers to come about as rapidly as possible.

4. Conclusions

Low-tech industries constitute an essential part of the economy in several countries. Europe has a higher proportion of its output in so-called ‘mature’ industries than either the USA or Japan, and Norway has a much higher proportion than Europe as a whole. Providing knowledge on how these industries may sustain economic growth and welfare in the future, therefore represent a key policy issue. This study provides a detailed discussion on the impacts of political regulations on one such low-tech industry in Norway, the aquaculture industry.

It is shown that the transition of policies from the promotion of a labour intensive, atomistic business structure to the adaptation of a high tech policy, significantly has affected the competitiveness of the aquaculture industry. The changing political regulations have resulted in an increase in i) learning rates, ii) innovation and the abilities to transform and access distant technologies by establishing strong links to research intensive sectors. Furthermore it is shown that this development, in turn, has resulted in an augmentation of the ‘minimum efficient scale’ of fish farms. We review these issues in some detail below.

Low capital accumulation and new international potentials seen within the aquaculture sector, resulted in a shift in policies starting from about 1985. Essentially, three aspects were emphasised: i) dramatic Increases in governmental expenditure on R&D, ii) a continuos increase in maximum permitted pond volumes and iii) ownership liberalisation.

Ownership liberalisation resulted in increasing market concentration ratios and the attraction of capital to the sector. Looking indicators on innovative performance, it is seen that this development in turn resulted in an increase in innovative incentives and capabilities:

Labour productivity was more or less constant until 1987. From this year on it augmented rapidly. From 1987 to 1991 the output per man-hour increased by a factor 3.3. Furthermore, plotting output quantities and labour productivity and comparing it to the standard 80% learning curve, gives further insights. This comparison reflects a relative slow learning rate in aquaculture from 1978 until 1987. During this period the gap between the standard 80% curve and the aquaculture curve opens. From 1987 the gap starts closing, and the curves emerge in 1990-1991. From 1992 the learning rates in aquaculture well exceeds that of the 80% curve.

Looking to market concentration ratios this latter, dramatic increase in learning rates from 1992, may be explained. The CR4 index, the percentage of total output produced by the four largest firms, augmented from 5% in the late 80’s to 25% in 1994. Thus increases in learning rates may be explained by linking output quantities to learning-by-doing and learning-by-using. Holding total production constant, market concentration implies that companies increase their absolute output per year, thus their accumulated experience per year increases and they push faster down the learning curve. Within an industry where learning-by-doing and tacit knowledge[53] is crucial, knowledge is linked to *experience*. Therefore gaining experience faster than competitors is a key point to sustain competitiveness in this industry.

This observation do not necessarily mean that all low-tech industrial plants must be large in order not to be shut down. Very small farms do have advantages because the worker(s) usually know the plant by heart, having invested considerable time in the project and followed every detailed change in plant conditions. In aquaculture such an insight may for instance cause the worker(s) to detect abnormal behaviour of fish and diseases at a very early stage and thereby save costs. Furthermore very small plants do not necessarily utilise technologies that exhibit increasing returns to scale, thus having low capital intensity. A low capital intensity allows the small farms to regulate production quantities according to existing conditions. Most strikingly this is seen within fisheries where large boats with advanced capital intensive technologies are bound to fish large amounts in order to pay back their investments. This has resulted in a resource crises, where several species of fish are about to be depleted. Smaller boats, on the other hand, with low capital investments, are able to stay in business even in times when only small amounts can be taken out of the oceans. The above argument rather suggests that large farms are very important in order to be able to develop the cluster surrounding the low-tech industry. In low-tech industries it is generally the large farms which have the competence, experience and capital making them able to co-operate tightly with research and supply institutions in a interactive innovative framework. In turn, this cluster is crucially important for the development of the low-tech industry itself, *both for large and small plants.*

It is shown that technical change and the absorptive capacity in aquaculture made a positive jump in the period of rapid market concentration. From technical change based on ‘trial-and-error’ in the 70’s and the early 80’s, links to advanced scientific miles and supplier industries were made from the mid 80’s. These links made the aquaculture industry able to access and absorb technologies very far away from their core capabilities and close to the most advanced areas of technological innovation. Within this feedback system, innovations arise and technologies are transformed to meet the specialised requirements of different low-tech industries. This reveals two essential points about low-tech industries: i) these industries do not necessarily create or access new technologies via internal R&D, and ii) they often use inputs that are highly advanced and R&D intensive. By implication, it is very much the boundedness in the search process, the ability to connect to larger networks of knowledge infrastructure and hence the absorptive capacity of the low-tech firms, that shape their technological opportunities. As shown above these abilities are also shaped policy regulations.

The feature described above is a crucial insight for policy makers. As the technological opportunities (within low-tech industries) are strongly shaped by the links to industry and science bases, technical change in these industries is also crucially dependant upon the existence of *national clusters* that are strongly

[53] This concept of tacit knowledge is explored by Collins in: Collins H. M., 1974, *The TEA set: Tacit knowledge and scientific networks*, Science studies 4, pp. 165-186. Collins H.M., 1993, *Expert Systems and the Science of Knowledge,* in The Social Construction of Technological Systems, edited by Bijker W. E., Hughes T. P., Pinch T., The MIT Press, London, England.

committed to the low-tech industry in question. In the case of aquaculture, it is shown that such a cluster has emerged within marine electronics, pond technologies, boat and offshore equipment, feeding systems and technologies depending on information technologies in general. Within these systems, Norwegian aquaculture farmers are both users and creatively transformers of new technologies, co-operating closely with supply and research knowledge bases. On the other hand within processing technologies, or refinement, Norway holds a very weak position. This is quite strikingly the case *both* for the supply industry and the farmers themselves. Further underlining the argument, Denmark and Island holds a strong position within *both* the creation of processing equipment *and* within the consumption and utilisation of processing equipment. Actually, partly due to excellent processing skills, Denmark creates as many jobs on the basis of Norwegian fish as Norway[54]. By implication, to alter the situation it is important to establish strong Norwegian clusters and supply industries, widely serving the processing sector, in order to enhance rapid interactive learning within an innovative frame[55].

Finally it is shown that the rapid technical change experienced within the aquaculture sector, has augmented the 'minimum efficient size of fish farms'. This has some implications for the environment, as larger farms contaminate the sea more than smaller ones. This development is on some way balanced by ownership liberalisation and by market concentration. A simple theoretical argument shows that incentives to contaminate decreases with market concentration. Some empirical evidence underline this statement. The amount of medicine and antibiotics utilised, which reflects in the health of fish and hence water conditions, has dramatically decreased hand in hand with market concentration.

The future of Norwegian low-tech industries and its ability to innovate and absorb new technologies, will very much depend on its ability to expand its search process. The horizon in this process is heavily shaped and restricted by the competitive environment imposed on the low tech industries by the government and by the commitment of public and private research and supply institutions. Today some of

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[54] Djuve, A.B. and Steen A. H., 1994, *Norsk fisk - dansk produkt?*, FAFO rapport nr 143, Oslo, Norway.

[55] The importance of user-producer relationships are also explored in several other studies as: B. A. Lundvall, 1988, Innovation as an interactive process: *From user-producer interaction to the national system of innovation*, in Technical change and economic theory, edited by G. Dosi, C Freeman, R. Nelson, G. Silverberg and L. Soete.

See aslo B.A. Lundvall, , National Systems of Innoavtion

and Porter M. E., 1990, *The Competitive Advantage of Nations*, The Mac Millan Press Limited, London, Great Britain.

the most important of these institutions and firms, which serve the aquaculture sector, originate from offshore, oil and fisheries. Accordingly, some of the most important *innovations* in the aquaculture sector have links to these three sectors. More remote technologies depending on optics, acoustics and information technologies in general are also consumed and transformed within the aquaculture sector, but nearly without exception, these technologies are accessed through the described institutions. This emphasises the importance of establishing a fine grained technological and scientific knowledge infrastructure in order to enable low-tech industries to access new, advanced technologies, and to survive in increasingly competitive environments.

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STEP group

STEP-gruppen ble etablert i 1991 for å forsyne beslutningstakere med forskning knyttet til alle sider ved innovasjon og teknologisk endring, med særlig vekt på forholdet mellom innovasjon, økonomisk vekst og de samfunnsmessige omgivelser. Basis for gruppens arbeid er erkjennelsen av at utviklingen innen vitenskap og teknologi er fundamental for økonomisk vekst. Det gjenstår likevel mange uløste problemer omkring hvordan prosessen med vitenskapelig og teknologisk endring forløper, og hvordan denne prosessen får samfunnsmessige og økonomiske konsekvenser. Forståelse av denne prosessen er av stor betydning for utformingen og iverksettelsen av forsknings-, teknologi- og innovasjonspolitikken. Forskningen i STEP-gruppen er derfor sentrert omkring historiske, økonomiske, sosiologiske og organisatoriske spørsmål som er relevante for de brede feltene innovasjonspolitikk og økonomisk vekst.

The STEP-group was established in 1991 to support policy-makers with research on all aspects of innovation and technological change, with particular emphasis on the relationships between innovation, economic growth and the social context. The basis of the group's work is the recognition that science, technology and innovation are fundamental to economic growth; yet there remain many unresolved problems about how the processes of scientific and technological change actually occur, and about how they have social and economic impacts. Resolving such problems is central to the formation and implementation of science, technology and innovation policy. The research of the STEP group centres on historical, economic, social and organisational issues relevant for broad fields of innovation policy and economic growth.