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Natural resource industries, 'tragedy of the commons' and the case of Chilean salmon farming

Michiko Iizuka and Jorge Katz

United Nations University – Maastricht Economic and social Research and training centre on Innovation and Technology
Keizer Karelplein 19, 6211 TC Maastricht, The Netherlands
Tel: (31) (43) 388 4400, Fax: (31) (43) 388 4499, email: info@merit.unu.edu, URL: http://www.merit.unu.edu

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Michiko Iizuka
UNU-MERIT
Iizuka@merit.unu.edu

Jorge Katz
University of Chile
Jorge.katz2@yahoo.com.ar

Abstract

Chilean salmon farming has been considered as an outstanding example of success after growing at two digit rates for more than twenty years. With further insight, we now know that such rapid process of expansion came at the expense of sanitary and environmental deterioration. The outbreak of ISA– a viral disease that kills salmon - in 2008 has made this utterly clear. The overexploitation of the ´common´ - pristine waters – upon which the industry operates, and the lack of an adequate regulatory mechanism monitoring environmental impact contributed to a gradual – but not always adequately perceived – long term decay of industry performance. The paper shows that industries based on the exploitation of a CPR – common pool resource – require a quite different analytical approach than the one conventional neoclassical theory offers us for the understanding of firm and industry behavior. Our study shows that industries of this sort require location specific know how and R&D efforts plus public/private cooperation in order to maintain long term sustainable growth.

Keywords: common pool resources, 'tragedy of commons', natural resource based industry, Chile

JEL code: Q22, Q57, L22

I. Introduction

The Chilean salmon farming industry experienced a dramatic downturn since 2008 with rapid spread of a viral disease (ISA), which affects salmon's self-immunological capabilities, eventually leading it to death. With the benefit of insight we now know that the long term decay of the industry has been the outcome of a complex episode of gradual productivity loss started in midst of hype in international price of salmon due to the gradual deterioration of the water quality where salmon was being cultivated. The reason for this is a typical situation in which individual firm's profit maximization – associated to increasing fish density in the cultivation ponds – triggers off industry failure as a consequence of overexploitation of the ´common´ – pristine waters. An abnormally high fish density in the ponds favors the horizontal transmission of pathogens and vectors, which operate freely in the waters. This situation suggests a typical 'tragedy of common' scenario, closely resembling the one described by G. Hardin in his 1968 Science article.

The purpose of this paper is to examine the economic and institutional circumstances that eventually developed into a systemic collapse, looking at firm as well as industry as a whole. Salmon farming is based upon a highly particular and country-specific set of biological and environmental variables that require location-specific knowledge and understanding, and a set of institutions capable of governing the ´common´. It is important to understand that neoclassical production theory is helpful in explaining firm behaviors under more conventional environment; however, not particularly so in the case of activities where biological and environmental forces account for a significant degree of uncertainty and dynamic variation in production condition. The former is based upon the robotic-like behavior of a single ´representative firm´ that optimizes profit under the constraint of a given set of exogenous parameters. There is limited perception on disequilibrizing factors such as local carrying capacity and regulatory forces conditioning the functioning of the firm-end of the industry. For instance, salmon farming companies grow a fish in captivity under highly imperfect information. The local specific knowledge and sector specific understanding of the biological, genetic, environmental and oceanographic conditions are required to ensure adequate production organization. In other words, the final result of their production activity is strongly probabilistic and loaded with uncertainty subject to local conditions. It is a far cry from the deterministic model illustrated in conventional production theory. Evolutionary economics (Nelson and Winter, 2002) and political economy of common pool resources (Ostrom, 1990) may offer alternative approaches to understand why firm behaved self-destructive way in a long run. If we are to understand firm and industry behavior under such particular circumstances, many new questions of an organizational and institutional nature would open up which demand location specific examination.

The paper is divided in four sections. Section 2 presents a theoretical review of received literature concerning natural resource based industries, economic governance in scenarios where CPR - common pool resources – prevails and understanding of evolutionary economics is discussed to set the framework. Section 3 describes the behavior of Chilean salmon farming companies paying special attention to the country-specific forces that have affected long term behavior of company and institutions. In this section we present empirical evidence collected during the course of a field study conducted in mid-2009. Finally, section 4 draws various conclusions and policy implications of our research.

II. Theoretical review

2.1 Natural resource based industries and developing countries.

Natural resources are considered as ‘curse’ or impediments for development in fields of social science in the early stages of Development Economics (Prebisch, 1950, Singer, 1950, Sachs and Warner, 1995, 1997, 1999). Under the impact of recent rapid advance in biology, genetics and other various sciences related to the exploitation of natural resources, some international organizations have suggested that natural resource based industries can be an ´engine for growth´ as they involve a strong potential as carriers of new technologies. (De Ferrati et al, 2002; ECLAC, 2003). The relevance of natural resource based industries as locus for knowledge generation activities has been pointed out by several studies (Athukorala and Sen, 1998, Owens and Wood, 1997, de Ferrati et al., 2002, von Tunzelmann and Acha, 2005). Moreover, Katz (2004) pays particular attention to the importance of local knowledge generation activities in natural resource based industries. Katz states that these activities demand country-specific knowledge generation efforts if they are to operate efficiently and that they cannot rely on imported know how and foreign technological blue prints if they are correctly to adapt to local production conditions.

It is important to understand that natural resource based industries quite frequently operate on the basis of common pool resources (CPR), as it is precisely the case with salmon farming. The economics and governance of CPR-based sectors opens up an interesting topic for examination, to which we now turn.

2.2 Management of common pool resources (CPR)

Management of common pool resources (CPR)[1] generates an inner tension that develops between an individual user (in this case, a firm) and its profit maximizing behavior and a group of users (in this case, narrowly defined as an industry) and its collective performance. As each individual user attempts to maximize his/her private use of the ´common´ eventually he/she inflicts welfare loses to the rest of the group by depriving others from accessing to the ´common pool´ (Feeny et al, 1990, Ostrom et al 1999). In 1968, Garret Hardin[2] presented a simple example of herder's behavior. By putting one more cow in a limited space of land (common), the individual maximization lead – through the eventual overloading of the resource – to a reduction of the collective benefits of all users of the ´common´. His paper - called ´the tragedy of the commons´- emphasized the possibility of two different governance models for CPR: (1) government regulation (role of state) or (2) exclusive private property regulating access to CPR(role of market).

Ostrom (1990) considers Hardin’s example as grossly “over simplified” and claimed that some social groups—including herders—can learn and struggle successfully against the threat of resource degradation through developing and maintaining self-governing institutions. Feeny et al (1990) demonstrated, through the review of case studies, that neither state control nor markets work perfectly in favour of long term sustainability of the ´common’. Solving the problem of CPR requires actions mainly to: restrict access and create incentives for users collectively to invest in ´preserving the resource instead of overexploiting it’ (Ostrom et al, 1999). Such a positive outcome requires an adequate combination of public and private partnership or collective action. Important to this argument is the fact that stakeholders in the common *can 'learn' from interactions and therefore develop institutions capable of preventing the tragedy of the commons*. For enabling the sustainability[3], they have to act collectively for common purposes (Ostrom, 1990).

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[1] Common pool resources (CPR) include those property that can have excludability—it is costly to exclude others from using the resources—and subtractability—each user is capable of subtracting from the welfare of other users (Feeny et al, 1990, Ostrom et al 1999) Examples include fisheries, wildlife, surface and groundwater, range and forests.

[2] Similar idea to his was already presented by Gordon in 1954 and Scott in 1955 even earlier by Lloyd in 1830s (Feeny et al 1990 and Hardin, 1998)

[3] Sustainability is defined as “maintaining the capacity of the joint economy-environment system to continue to satisfy the needs and desires of humans for a long time into the future” (Common and Stagl, 2005:8)

Following Ostrom's study (1990), research on management on CPR concentrated in identifying the blueprint conditions for successful collective action to take place via massive review of case studies [4] (Poteete and Ostrom, 2004, Agrawal, 2001). Nevertheless, as Agrawal (2001) criticizes, these efforts concentrated only on the 'ecology-human' interaction and overlooked important external factors – such as markets, technology and population pressure to name a few– that have a strong and long lasting impacts on the way CPR is managed.

Coming with above realization, the idea of finding a general blueprint for successful CPR management had gradually being abandoned (Poteete and Ostrom, 2004:454). They state that, "given the wide variety of characteristics that groups possess, as well as the diversity of ecological conditions they face, rules that work well to facilitate collective action in one case may not work well in other cases." (ibid:454). They argue that sustainable management of CPR involves a "struggle" for legitimacy that is only obtained from an adequate distribution of benefits and costs among stakeholders in each particular case.

Recent studies on CPR management; therefore, emphasizes that successful management requires *local specific institution which can co-evolve* with changes in a broader set of global as well as local forces where CPR is embedded (Dietz et al, 2003, Ostrom et al 1999). Dietz et al (2003) argue that individual actors and global systems are interlinked in complex and multi layered manners. Steins and Edwards (1999) propose nesting multiple platforms for resource negotiation with multiple users of commons. Ostrom (2009) attempted to create a general framework to analyze sustainability of social ecological systems. Hollings et al (1989) recognized that managing CPR is a problem of a systemic nature where "aspects of behavior are *complex and unpredictable*". He states that CPR management is "*non-linear in nature, cross-scale in time and in space, and has an evolutionary character.*" He believes that both natural and social systems develop "critical feedbacks across temporal and spatial scales" (ibid: 352). What is interesting here is that all of the above authors focus on co-evolving relationships between ecological and socioeconomic systems paying attention to a wider set of forces that might influence the management of CPR. They furthermore state that sustainable economic activities involving CPR need institutions that link the environmental and socio economic forces in a ´location-specific´ way while paying attention to global impacts. However, it is also true that such institutions may not emerge naturally and might require some public sector coaching

[4] Such as "conditions of a resource, and of the users of a resource, that are most conducive to local users self-organizing to find solutions to common dilemmas." (Ostrom, 1999:495).

and regulation to induce behavioral change and collective action among stakeholders. For such collective action to emerge, presence of trust and social capital among the stakeholders are considered crucial(Coleman, 1988).

The management of CPR also requires understanding of local carrying capacity. The carrying capacity is generally discussed as from four different angles of demography, economics, ecology and epistemology, (McMichael et al 2003). It is with regards to local contexts, that the four different dimensions of carrying capacities can be coherently integrated for the understanding of sustainable management of CPR. In operational terms, understanding local carrying capacity would also require collaborative efforts of various experts and organizations.

2.3 Evolutionary theory of firm

Evolutionary economics looks at the process of economic transformations of firms, industry organization and institution paying attention to the role played by divers agents based on their experience, and interaction among them. Evolutionary economics differs from neo-classical economics in various ways but fundamentally by their disbelief in economic equilibrium. It considers that economic development is in constant disequilibrium due to the presence of entrepreneurs who innovate to stay competitive in the market (Schumpeter, 1934). Nelson and Winter (1992) looked at the changes in technology and routines as firms go though process of selection, increase in variety and establish routines. The market has an important role of selecting successful firms who could obtain more market share through competition while unsuccessful ones fall behind or are eliminated. The result of competition in products and practices is determined by routine: the standardized patterns of actions implemented by the firm. Both market and firm change and co-evolve constantly thereby they are in state of constant disequilibrium.

The successful firm in neoclassical economics is that achieves profit maximization through price-based competition. Evolutionary economics introduces non-price competition through other factors such as quality of innovation. In real life, the firms do not compete solely on the basis of price but also through innovative activities. The evolutionary economics views the process of firm' survival as dependent from how effectively firm can learn and unlearn the routines as the firm co-evolves with the market. Neoclassical economics assumes that there is universal rationality and information symmetry in learning process while evolutionary economics casts doubt on their proposition as firms' rationality is "bounded" and complex due to different forms of production organizations.

There is an important distinction between competence and capability with regards to firm's ability to change (Nelson and Winter, 2002, von Tunzelmann and Wang, 2007, von Tunzelmann 2009). Nelson and Winter (2002) do not make clear distinction between competence and capability. However, they state that the competence is "achievable where skills and routines can be learned and perfected through practice" (Ibid:29) while from the evolutionary point of view, the importance is to be placed on how the firm can handle contrasting demands in different types of situations through learning process. von Tunzelmann (2009) makes more explicit comparison where he considers that capabilities are "directly involved in transformations" (ibid:446) while competencies are "previously transformed and are hired or otherwise bought into assist in the ensuing process" (ibid: 446). He sees capability as more closely associated with 'dynamic capability' (Teece, Pisano and Shuen, 1997) that enables firms to transform in co-evolutional fashion.

Similarly, with reference to firm related activities, Katz (1987) makes distinction among different capabilities such as operational capabilities in production, investment capabilities and innovation capabilities. Viotti (2002), in attempt to establish framework to understand technological change through comparative study of South Korea and Brazil, makes distinction between production capability, improvement capability and innovation capability in his study of 'National learning system'. He distinguishes the technology absorption pattern into 'active' and 'passive' learning and considers that active learning pattern enables innovation and is compatible with "Schumpeterian development". As shown above, various attempt to distinguish the ability of firm to perform efficiently from ability that enables to dynamically change and adapt to a changing environment.

Much of the discussion made so far on evolutionary economics is largely based on experiences of manufacturing industries in which the firms capacity to interact with the market and co-evolve with it is the most important factor. There is no mentions about environmental sustainability or discussion of management for CPR, which may—in case of natural resource based industry—have larger role in restrict or restrain firm's activity and have strong influence in determining the trajectories of technological development. This is in contrast to the literature on management of CPR. The literature on management of CPR recently started to look at more holistic interaction between 'ecology and the rest' in systemic way but much of it is still in the black box. In the industries based on natural resources sustainability of CPR, plays a crucial role for determining the 'survival' of firm as well as the industry. However, in the evolutional theory of firm, due to its case studies being concentrated in manufacturing activities, does not seem to have paid enough attention to the sustainability aspect for the industries based on natural resources. The industry based on natural resource; may therefore constitute a different co-evolutional firm from that of manufacturing because co-evolution must take place among market, CPR and technology to establish the new routines.

Recent literature indicates that natural resource based industries can be an ´engine for growth´ in developing countries. However, such engine is dependent upon good management of CPR. When we look at the CPR literature, the discussion currently focuses on the importance of institutional arrangements to restrict access and create incentives for user (firms) to invest in protection of the resource rather than engaging themselves in overexploitation of the ´common´. Furthermore, successful management of CPR is currently viewed more holistically to include a wider set of forces pertaining global markets, science and technology, and more. Identification of local carrying capacity is a complex task of finding equilibrium between ecology and human behavior. The power of enforcing strict regulatory rules and way in which the enforcement is carried out have important role in determining such co-evolutionary process. The presence of trust and social norm—social capital—is considered essential for the management of CPR to draw collective action. The evolutionary theory of firm, unlike the neoclassical one, emphasize the importance of co-evolving nature of market, technology, and firm to transform routine and present a useful framework to understand transformation of firm and industry.

IIII. Case of Chilean salmon industry

3.1 Chilean salmon farming and the recent sanitary crisis

Most studies on the Chilean salmon farming industry stress two major facts. On the one hand, the important role the Chilean public sector played in the original inception of the industry and, on the other, the major role learning by doing and technology adaptation efforts had during the initial stages of industry expansion (Katz, 2004, Iizuka, 2007, Maggi, 2002, Montero, 2004). In this paper, we shall not spend a great deal of time looking at historical events. Rather, we shall concentrate in examining the recent sanitary and environmental crisis in order to illustrate the extent to which lack of understanding about management of CPR underlies much of what has happened as far as salmon farming in Chile is concerned.

(1) Demography of salmon farming firms before the crisis in 2008

By the early 2000s salmon farming in Chile had reached the status of a mature oligopoly in which 5 firms produced more than 50 % of industry output and a similarly high share of exports. The gap between ´large´ and ´small´ firms increased significantly during the late 1990s even in spite of the fact that new entrants joined the industry in the initial years of the new century. We can divide salmon farming firms into three groups of firms. First, ‘traditional firms´ those established during the initial years of industry inception in the 1980s. Second, ‘traditional´ SMEs and, lastly, new firms entering the industry recently, many of which arrived from other industries, such as industrial fisheries. Major differences in production organization and in company ´culture´ prevail between these three different salmon farming companies. SMEs control one or very few cultivation concession sites and this makes their production organization quite rigid and inflexible. On the contrary, ´large traditional´ salmon farming companies own a large number of cultivation permits and can program the geographical distribution of production according to the physical distribution of concession sites they control. As far as new entrants is concerned, many of them regard salmon farming as a portfolio investment option, and were attracted by the high rate of profit the industry attained in recent years. Vignolo et al (2007) mention that the increasing diversity in management ´culture´ and production organization induced by recent new entry might have resulted in the erosion of intra-industry trust and cooperative efforts – social capital—*vis a vis* the early period of industry inception in the 1980s. According to this view, the increasing diversity in stakeholder composition might have negatively affected collective action aiming at protecting the ´common´. (Ostrom, 1990).

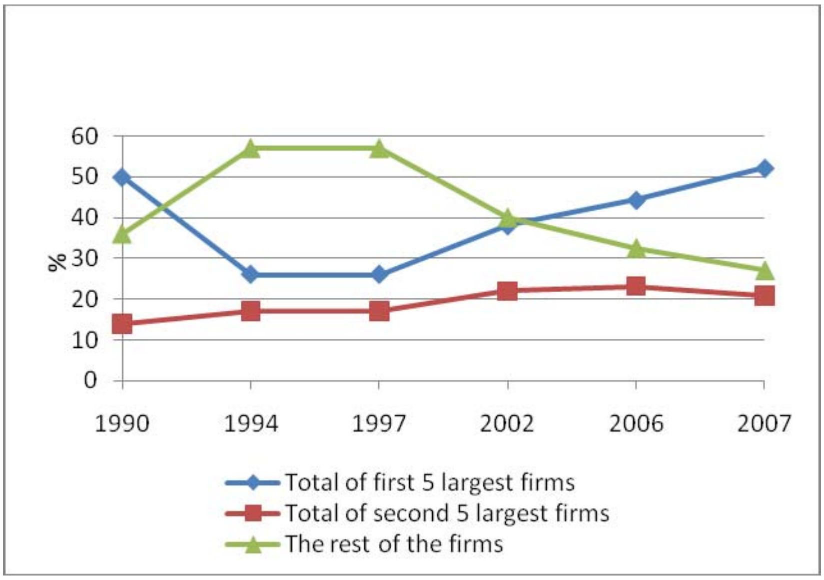

Figure 1 Export share by size of firms

Source: AquaChile

Table 1: New firms entering into salmon industry in the 2000s

Firms	Activities	Year entered	Investments (e) millions of US$	Productions 000 tons	area of operation	Other activities	Origin
Salmones el Golfo	Cultivation center	2005	80	20	XI	Mussels/ extractive fishery	Chile
Salmones Humboldt	Cultivation center	2006	70	20	X	Mussels	Chile
Salmones Itata	Cultivation center	2006	60	30	XI	Mussels/ extractive fishery	Chile
Salmones Cupquelan	Cultivation center	2004/08	80	40	XI		Iceland /Canada
Salmones Aysen	Cultivation center	2007	15	25	XI		Chile/USA
Provi. Fish farms	Cultivation center	2006	5	3	XI	Extractive fishery	Chile
Riverfish	Cultivation center	2007	50	18	XII		Chile
Tornegaleones	Cultivation center		25	20	XII		Chile
Foodcorp S. A/ Pacific seafood	Cultivation center	2008			XI		Norway
Acuimag SA	Fresh water phase	2007		….	XII		Chile

Source: Create based on various articles in Revista Aqua

(2)Magnitude of ISA crisis

The industry suffered a dramatic downturn at the beginning of 2008, due to the rapid spread of ISA. The impact of the crisis was not limited to salmon farming firms themselves but it rapidly reached intermediate input and production services suppliers. Close to 20 thousand jobs were lost in the short period of two years and numerous coastal villages whose socio economic functioning was entirely based upon the demand for skilled and unskilled labor by salmon farming companies were rapidly thrown into a high degree of social disarray.

By 2010, the production of salmon had fallen to around 200 thousand tons down from a peak of nearly 700 thousand tons in 2006. By 2009 close to 60% of the cultivation centers were out of production. What started as a sanitary and environmental crisis very soon developed into a financial one as many firms simply could not serve their debts to the banks. Their working capital evaporated rapidly as salmon continued to die in the cultivation tanks, or were processed and exported before complete maturity to avoid the risk of infection. Many firms came close to bankruptcy with banks now unwilling to extend their credit facilities in order to finance a new cultivation campaign. Under such circumstances a significant process of ´de-clustering´ emerged, with production service suppliers – veterinarians, divers, net repairing personnel and more – moving out of the region in search for new job opportunities. El Mercurio,- the largest Chilean newspaper - estimated that the standing debt of the industry with the banking sector came close to US$ 2,000 million by 2009, that is nearly one year worth of exports.

(3) Direct cause of the crisis

It is commonly believed that the ISA virus was the source of the crisis. It is said that the virus came from Norway embedded in imported salmon eggs. Although the first outbreak of ISA was reported by the local subsidiary of the Norwegian firm, Marine Harvest; many local specialists believe that a variant of the disease was already present in Chile for sometime until certain environmental conditions – high density of fish in cultivation tanks, for example – induced its mutation and rapid spreading.

The evidence suggests that decaying sanitary condition started even before ISA actually became epidemic. During the initial years of industry inception – 1980-89 – very few episodes of disease were reported. The industry grew quite rapidly during the 1990s, reaching 200 thousand tons per annum at the end of the decade. *Pari pasu* with the expansion of production the diffusion of pathogens became more noticeable. An independent survey of the sanitary situation carried out by mid 1990´s by local veterinarians confirms the fact that the sanitary situation was worsening even before the ISA episode had even started.

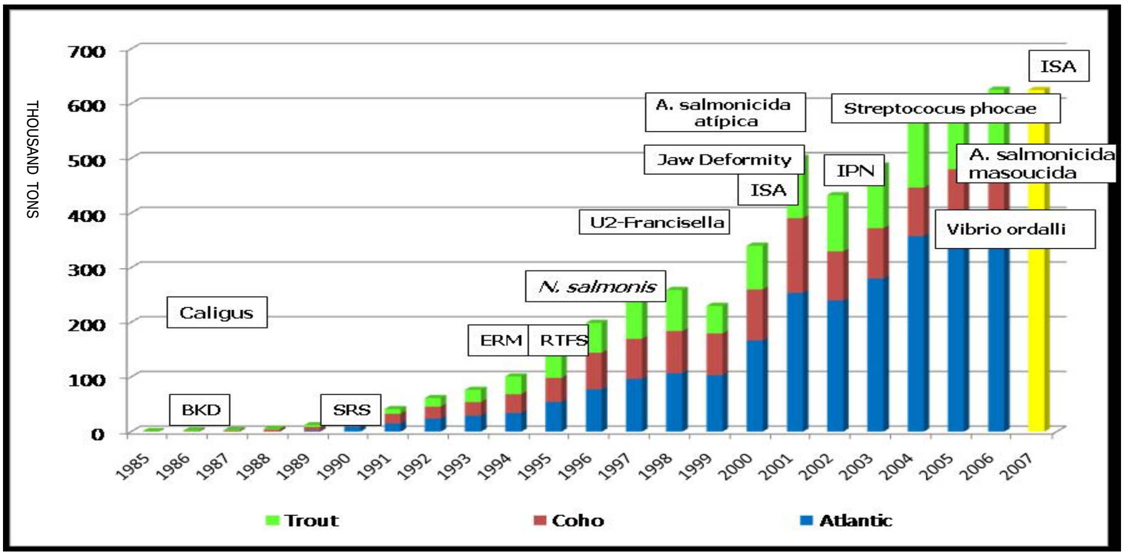

Figure 2 Diffusion of pathogen and production volume

Source: obtained from Dr. D. Nieto, 2009

Table 2 Emergence of new diseases in Chilean Atlantic salmon

Disease	6-7 years ago	Today
Bacterial kidney disease	X	X
Piscinketsiosis		X
Infectiouspancreatic necrosis	X	X
Vibriosis (v.ordeli)		X
Vibriosis (v.angillarium)		X
Ulcerative vibriosis		X
Streptococosis		X
Franciseltosis		X
Atypical furunculosis		X
Kudoa		X
JanDrice synDrome		
Nucleospondiosis	X	X
Flavovacteriosis	X	X
Columnaris	X	X
Yersimiosis	X	X
Saprolegiosis	X	X
Caligus	X	X
ISA		X
Amoebic gill disease.		X

Source: P.Bustos, manejo sanitario integral en centros de agua dulce. Skreting, Nov. 2008

Local biologists and veterinarians (Dr. D. Nieto, Dr. P. Bustos, Dr. S. Bravo, Dr. C. Wurmann) interviewed during the course of our fieldwork speak about the 'ecological triad of illness' to refer to the interaction between the host (fish), the environment, and the various pathogens acting in the environment. According to them, 'becoming ill' constitutes *prima facie* evidence that the state of equilibrium that normally obtains between the three components of the triad breaks down reducing the self-immunological defense capabilities of the fish. This is when the pathogen acts, infecting one or a few fishes first and then quickly spreading to the whole population in the cultivation tank. In other words, even if it is true that the impact of ISA virus has been quite strong that shouldn't induce us to believe that other sanitary and environmental problems were not present even before the outbreak of ISA and were gradually affecting the functioning of the industry, its long-term productivity and sustainability. In other words, the crisis is not just the consequence of ISA virus but the cumulatively result of sanitary and environmental mismanagement which has been present and worsening, for many years before the outbreak of ISA.

3.2 Micro evidence concerning the determinants of the sanitary and environmental crisis

(1) The economics of salmon farming

Cultivating salmon, a carnivorous fish in nature, in captivity involves complex process. It is important to maintain welfare and health of fish as these conditions affect productivity through its rate of growth and mortality. To balance welfare and health of fish require location-specific knowledge and cannot be considered as standard and universal as sometimes economists do in relation to manufacturing production. Rearing salmon in captivity demands a great deal of generic as well as local specific scientific and technological understanding, which cannot simply be obtained by importing foreign know how and technological ´blue-prints´.

Salmon farming firms operate with ´batch´ production organization arrangements. They ´cultivate´ fish in a semi-open enclosure until it gets ready for harvesting. This takes close to 15 months depending on the species we consider. The fish is ready when it reaches a certain weight (usually 3.5 kg on average). If a conventional cost/ benefit calculation is applied, timing for harvesting is reached when the marginal cost of maintaining the fish in the enclosure equals marginal revenue. The decision is made comparing feeding costs, other intermediate inputs, market value of salmon and the rate of interest. Thus, equilibrium for the individual farmer is reached when the proportional increase in salmon price – net of feeding and harvesting costs—

equals the opportunity cost of further maintaining the fish in the cultivation tank.

We notice that firm behavior is determined by two quite different sets of forces. On the one hand, biological and genetic forces, which determine the growth rate of salmon, its rate of growth and mortality to name a few. Even within the same 'batch' (cohort), each individual fish grows differently from the rest due to genetically inherited conditions, nutritional contents of feed and else. To certain extent, producers can control the incidence of these genetic and biological forces by selecting high quality smolts for cultivation. However, it is not possible, to completely eliminate the biological and genetic variability within each 'batch'. On the other hand, firms also make strategic decisions concerning production methods, fish density in the enclosure, bio-security measures, daily food ration, energy content of the diet, nature of the feeding process, food supplement, vaccination, medication, feeding techniques to name just a few. The interaction of these two sets of determining forces determines firm productivity. It needs to be understood that the impact of these variables is dependent upon the initial genetic and health conditions of each cohort of smolts, as well as from other local contextual factors, such as oceanographic conditions, i.e. ocean depth, strength of water currents, nature of the seabed, nutrients and oxygen in the water, water temperature, and more. Together with the previously mentioned ones these variables also affect individual firm productivity. Many of these variables are clearly outside the control of firms so companies are required to operate with simple ´rules of thumb´ with a great deal of trial and error.

In other words, unlike manufacturing industry, in which production routines can be assumed to be fairly stable and predictable production, routines in aquaculture are extremely variant and reflect the various aspects of environment with high degree of uncertainty. Salmon farming constitutes a typical production activity in which uncertainty and the volatile nature of biological and environmental conditions systematically affect production outcome. For this reason, the standards text book theory of the firm is scarcely useful when we come to understanding long term company behavior in this area of manufacturing production.

(2) Firm behavior leading to the sanitary and environmental crisis

As mentioned earlier, the ISA crisis did not happen just because of the spread of the pathogen. It required certain conditions (health of fish, density of pathogenic agents in the water, fragility of sanitary conditions and more) to reach the threshold level for the disease to become epidemic. This section will look at firm behavior and underlying factors that led to the crisis.

(a) Concentration of cultivation centers in small geographical areas

Currently, three quarters of the salmon farming concessions granted in Chile are located in a small territory covering no more than 300 kms2. The concentration of cultivation center in Chile is striking if compared with the Norway, which has total area of 1.700 kms2 for total cultivation area. Despite the limited areas of territories used for farming, there were no regulations monitoring distance between salmon farming centers (currently 2.2778m) until RAMA (Reglamento Ambiental para la Acuicultura) was enacted in 2001. As the result, cultivation centers in Chile are much more densely situated than in Norway[5]. The concentration of cultivation center in a very small territory is also caused by several factors including: lack of physical infrastructure (such as road and port) connecting the cultivation centers to fish processing plants or to transport inputs (feeds, equipment etc), lack of human resources to work in the centers and a short supply of public services such as school and hospitals for the families of employees working for the industry. Such lack of human resources, public services and infrastructure resulted in the concentration of cultivation sites in limited geographical areas.

(b) Increase of fish density in cultivation centre

The production of salmon in Chile increased dramatically from 1999 onward. By 2006 it had reached an all time historical peak, at just about the same output level than Norway, the biggest exporter (figure 3) in the world. The strong incentive to increase production came from the rapid raise of world prices from 2001 to 2002 as a result of the diffusion of the avian flu. The average price of salmon increased from around US$3 per kg in 2003 to approximately US$6 per kg in 2006 (figure 4). In our view, such price increase and its impact upon profit margins induced many local firms to increase fish density in their cultivation tanks.

[5] This was confirmed in the recent public lecture by Mr.Puchi, of AquaChile SA - the largest Chilean salmon farming firm. He confirms this point by saying that: ´production is 50% larger per concession in Chile while total cultivation area is 70% smaller´ (H. Puchi: El salmon Chileno, experiencia historica y futuro. April 2009).

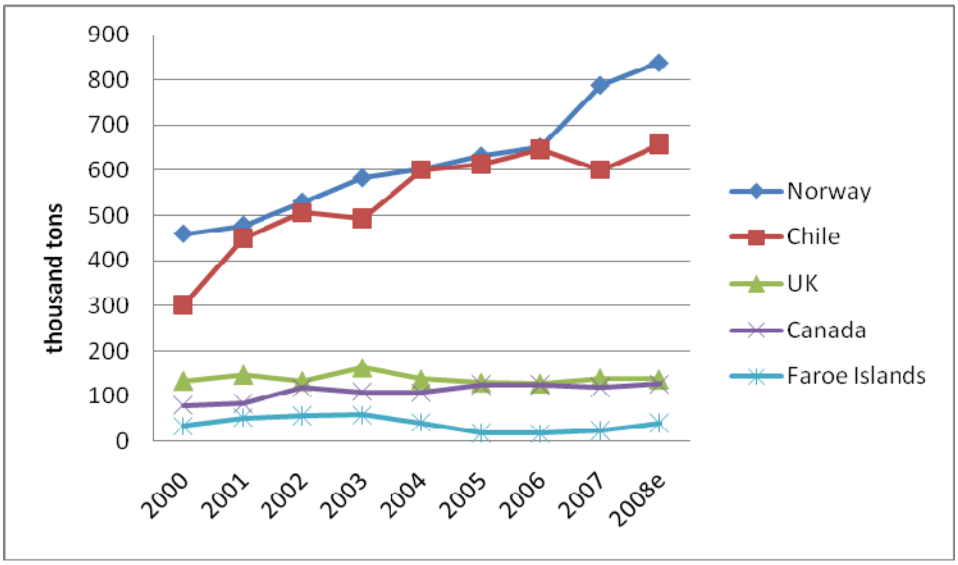

Figure 3 Evolution of Chilean export with major exporters

Source: SalmonChile, 2009

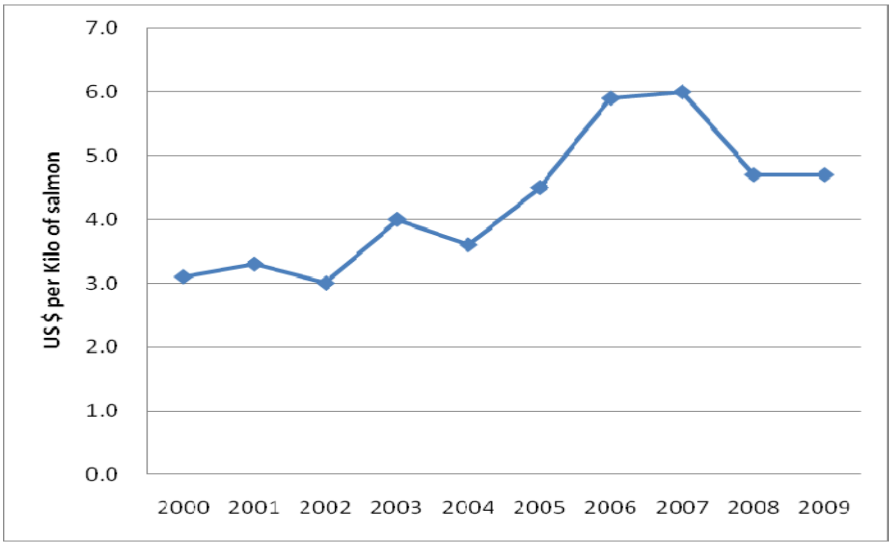

Figure 4 Fluctuation of average price of salmon

Source: SalmonChile various years

The data (table 3) indicated that each cultivation centers is larger in Chile than in Norway in terms of volume of fish per centre (table 3). Ewos data – a salmon food company – effectively shows that the average number of fish per cultivation center increased quite significantly (figure

5) since 2003. In other words, salmon farming companies behaved quite similarly to Hardin's herder: increasing the volume of output out of a given cultivation tank. i.e. adding 'one more fish' to a fix unit of the resource. Moreover, as the water is part of CPR affecting other firms in the area, the horizontal transmission of vectors and pathogens had to be a priori expected.

Table 3 Average salmon weight per cultivation centre: Chile and Norway

Chilean cultivation site	**Average weight** (tons/center)
Chiloe centro	1,136
Melinka	1,106
Chiloe sur	859
Estuario reloncavi	1,142
Aysen	757
Hornopiren	1,079
Cisnes	892
Seno reloncavi	1,076
Total	**1,021**
Norwegian cultivation site	
Finnmark	255
Troms	499
Nordland	528
Nord-trondelag	518
Sor-trondelag	522
More og fjordane	424
Hordaland	374
Rogaland	506
Ovrige fylker	689
Total	**474**

Source: EWOS, comparación de resultados productivos en salmón atlántico. Noruega-Chile. Mimeo, Puerto Varas, Chile, November 2007.

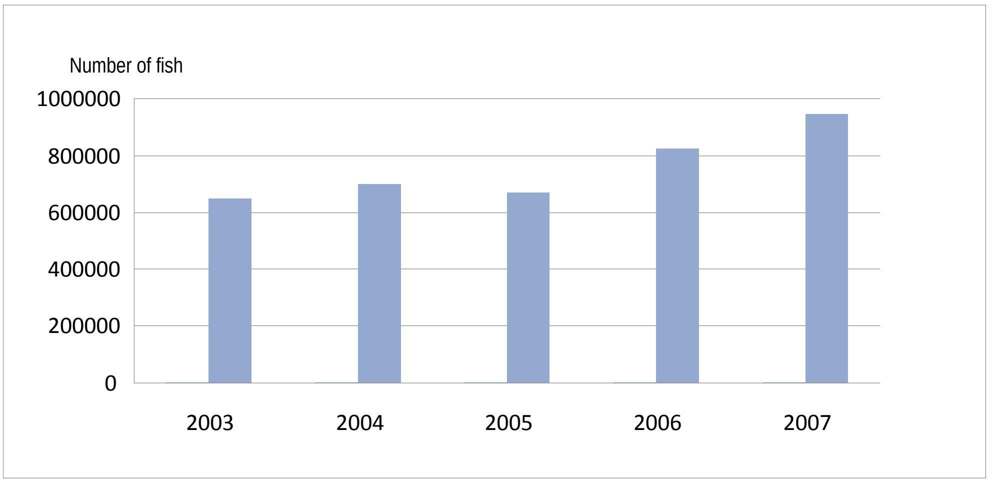

Figure 5 Average numbers of fish in each cultivation center (for Atlantic Salmon)

Source: EWOS, Comparacion resultados productivos Salmon Atlantico Noruega-Chile, EWOS Health, Puerto Varas, Nov. 2007

After a certain threshold increasing fish density in the tank worsens the 'environment' in which the fish is reared. It is true that outbreak of various diseases increased over the years with increase in production (see previous chart) but this evidence alone may not be enough to associate directly to the worsening of water quality and sanitary conditions. Data collected by EWOS provides circumstantial evidence of decreasing biological quality of CPR, the 'water'. Table 4 demonstrates the decreasing trend of productivity of firm in relation to 'water'. While the volume of salmon produced increased from 2003 onwards, other indicators of companies' productivity showed signs of deterioration. The average weight per fish at the time of harvesting declined from 4.4 kg to 4.1 kg; the number of days for harvesting prolonged from 487 days to 543 days; the amount of kg of salmon produced (output) per fixed amount of smolt or egg (input), both decreased from 3.71 to 3.14 for the former and from 1.3 to 1.1 for the latter, and so forth. This does not include additional expenditure on vaccines and antibiotics used to prevent fish from being sick for worsening sanitary condition or extra days of feed given for prolongation of harvesting time[6]. Both the economic and biological rate of conversion[7] show signs of deterioration going from 1.36 to 1.52 and from 1.24 to 1.34 respectively, indicating that more kilos of feed are necessary to produce 1kg of salmon. Figure 6 shows that the rate of fish mortality increased from 15% to 25% from 2003 to 2007. In a nutshell: all economic and

[6] See box 1 for more detailed estimate calculation for the loss.

[7] Economic conversion rate is the rate in which KG of feed converted into 1KG of salmon in economic value terms, Biological conversion rate is in biological terms.

biological indicators point in one and the same direction, i.e. industry productivity was declining from 2003 to 2007, even before the ISA disease started to spread in the midst of hype in price of salmon and production boom.

Table 4 Performance indicator of Chilean salmon industry (Atlantic salmon)

	2003	2004	2005	2006	2007
volume of production (000)kg	71,856	76,968	82,838	102,015	-
Kg/smolt	3.71	3.66	3.57	3.34	3.14
Kg/egg	1.30	1.28	1.25	1.17	1.10
Average weight at the harvest time	4,444	4,555	4,342	4,219	4,130
Economic factor conversion rate	1.36	1.40	1.38	1.42	1.52
Biological factor conversion rate	1.24	1.27	1.28	1.30	1.34
Days required unitl harvesting	487	497	484	488	543

Source: Comparacion resultados productivos Salmon Atlantico, noruega-Chile, EWOS Health, Puerto Varas, Chiel, Nov. 2007.

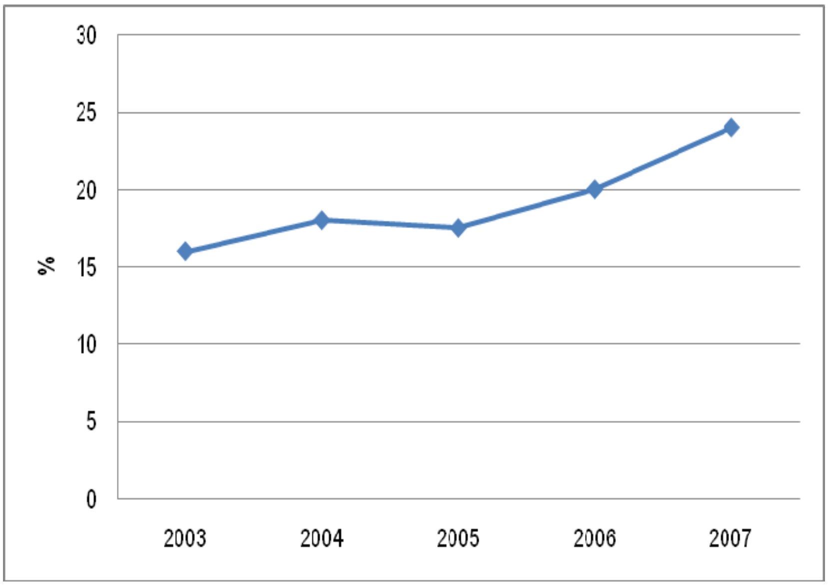

Figure 6 Mortality rate of salmon

Source: EWOS, op cit.

The export production volume soared from 2003 to 2006 and the sales of salmon increased; however, above economic and biological indicators show that such achievement is obtained in the context of a decreasing productivity of the resource—water—in which salmon is reared. Firms continued to increase production reacting to the increasing global price of salmon. Overall increase in volume of production, even taking into account the loss of output due to higher mortality rate still increased revenue because the (long term) marginal loss of productivity was valued less than the (short term) marginal gain from the increase in international price. In other words, decision of 'putting one more fish' in the pond was very much linked to—the volatile and changeable—global price of salmon while the cost of local sustainability—important factor for long term continuation of business—was significantly undervalued and not being incorporated in the co-evolutional development of the firm. Furthermore, collective action did not take place due to the deterioration of trust and social norm (social capital) among firms as mentioned by Vignolo et al (2007). The firms, instead of taking collective action to secure a long term sustainable path, opted for an alternative, more opportunistic path of short term profit maximization. On the basis of our previous discussion concerning CPR management, it is possible to say that there was an absence of institutional arrangements which restrict access to CPR and create incentive for user to invest in CPR instead of overexploiting.

The evidence so far presented allows us to conclude that the short term gains in production achieved from economies of scale and cumulative technological improvements – such as much larger cultivation tanks, digital feeding technologies and more--incorporated by salmon companies during the current decade, have been partially or totally eroded by the fall in the marginal productivity of the resource. Each firm behaved rationally maximizing profits in the context of given exogenous parameters but collective outcome resulted in failure as the CPR was not adequately taken care of. The biophysical aspects such as – health condition of the host, quality of the environment and pathogens—and the dynamic interaction among them need to be incorporated in the decision making process of individual companies even if these conditions are highly unpredictable *ex ante*.

3.3 Knowledge acquisition and organizational routine with regards to sustainability

One of the important ways to establish local knowledge infrastructure is to invest in R&D and research. Another is to promote diffusion of knowledge among the stakeholders to create local specific ‘common knowledge’ for the sector. In the early days, Chilean salmon firms acquired knowledge through 'learning by doing' and ‘trial and error’ processes. A great deal of ´incremental´ knowledge production was obtained in that way. We believe that in the initial phase of the industry local firms made a huge 'adaptive' technological effort facilitated by the presence of association and tight network of producers and Fundacion Chile, a public/private sector organization.

During the mid-1990s salmon firms became increasingly technologically intensive with use of imported capital equipments such as computers, automatic processing technologies, scientific food formulas, to name a few. The technological gaps *vis a vis* the international "state of the art' was gradually reduced at least as far as large local producers is concerned. As production process came close to ´world level´ standards organizational structures became more hierarchical, i.e. more ´distance´ obtained between company managers and cultivation tanks. (Based on interviews with Dr. D. Nieto, Dr. P. Bustos). The veterinary professionals and supervisors became more detached from the fish rearing process and their tasks became managerial ‘routine’ to achieve efficiency in operating cultivation centers. Conventional studies in other industries show that the accumulated impact of many ´minor´ changes in production organization eventually 'explain' a very high proportion of productivity gains at the shop-floor level (Katz, 1984). These also would evolve into capability to transform itself dynamically to a changing situation. It is quite likely that in the present case the same applies to the ‘non routine’ activities of veterinary professionals being in touch with fish rearing processes (as it occurred in the initial years of industry inception) may have helped enormously to understand the relationship of fish and local ecological condition and eventually contributed to the sustainability of industry[8]. The Chilean firms may have acquired ‘competence’; but they did not attain capability to deal with environmental sustainability.

In Chile, investment in R&D is very low when compared to Norway and Scotland. Nevertheless, this does not mean that Chile did not pay attention to knowledge acquisition and creation. In fact, this sector made conscious efforts in promoting innovation and research through public financing scheme. There are mainly two organizations financed R&D. One is the National Commission for Scientific and Technological Research (CONICYT) which financed Fondecyt. The other is Chilean Economic Development Agency (CORFO) financed Fontec &

[8] Of course, there are also isolated cases of successful local firms who have engaged in more profound and complex process of seeking new process technologies, products and organization of work, more respectful of local conditions. We insist, however, these are few cases in a vast number of situations where technology is copied and imported from countries like Norway, Scotland, USA or Canada.

InnovaChile[9]. Despite of efforts made to promote innovation and research in this sector, innovation projects supported by the CORFO have been focused on short term problem solving issues while the ones financed by the CONICYT was not fully utilized by the industry due to the lack of university-industry linkage (OECD, 2007). In sum, above industry and institutional evidence confirmed the earlier firm-level evidence that salmon farming in Chile was capable of enhancing competence for production; however, were limited in obtaining capability, the long term ability to change according external changes, using the definition by von Tunzelmann (2009). The funding for R&D is present and detailed analysis of the amount invested in R&D (Bravo et al, 2007) shows[10] that much of the research were conducted to enhancing productive technology but not on more fundamental basic research specific to Chilean context such as to understand the local carrying capacity.

From the standpoint of technological innovation, Chilean salmon farming firms became 'world class' in production. However, this was achieved without concomitantly developing domestic scientific and technological capabilities able to provide local solutions to emerging new questions of biosecurity, environmental sustainability, control of emerging pathogens and more. Producers established their international competence, importing equipment and production know how from abroad, but did not simultaneously paid attention to the specificity of local environmental conditions. This lack of attention to local sustainability is prominent feature for catching up countries in aquaculture such as Chile because most of the advanced countries[11] with long tradition in aquaculture have institutions that facilitate the management of CPR and promote domestic knowledge generation efforts adapted to local specific circumstances.

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[9] The total of finances made for aquaculture between 1983-2005 is $80,143,039 million Chilean pesos (approximately, US$ 17,000 million dollars) (Bravo et al, 2007)

[10] The analysis showed that there was emphasis on egg production, disease control etc; however, none was dedicated to the basic researches for finding out local carrying capacity for instance.

[11] For example, Norwegian legal framework explicitly ensures the long-term sustainability of local environment and business. They have two types of sources for the funds allocated to finance R&D in aquaculture: the funds granted by the government and fund created from the collection of royalties from concessions for the use of the common - or patents – by salmon farms. The funds provided by patents work through payment of royalty by the exporters of fish and fishery products. These funds are used in R&D projects that benefit the industry and are distributed in the form of subsidies. In this way, the state ensures creation of knowledge for managing CPR through investing in R&D and research. In other words, in Norway, where fishery has been one of the dominant economic activities, institutions balancing environmental and business interests were already systemically implemented. Other countries in which aquaculture plays a significant role –such as UK, Canada, Spain—also have institutions to promote research agendas focusing on environmental impact, health management and food safety (Bravo et al, 2007).

3.4 Regulatory institution for aquaculture

Chilean aquaculture regulation has not been organized in the way to effectively address improvement of firm´s sanitary and environmental practices. In fact, the first regulatory framework specific to aquaculture was enacted recently in 2000 and 2001. Due to its novel nature of this industry, sectoral knowledge of private sector is always more advanced than the public regulatory body. Furthermore, the public sector has placed more emphasis on developmental role than regulatory role to promote this new exporting industry. This is reflected in the fact that the National Fishery Service Agency (SERNAPESCA) did not have an independent regulatory body, resources and manpower to monitor firms with compliance with regulation until quite recently, in 2009. In sum, (1) the knowledge gap on fish farming process in public regulatory body; (2) emphasis on promoting exporting industry; (3) lack of resource and political will to monitor the firms to comply with regulation; had contributed to weak regulatory body that eventually contributed to the environmental collapse of this industry.

IV. Conclusion

Recent expansion of demand and rising world prices for natural resources has created a production boom for those countries endowed with natural resources. Without adequate institutional arrangement in accordance to the local carrying capacity, countries can lose valuable natural and environmental assets in an exchange for short-term economic gain, allowing the boom to bust as they engage into global trade.

The recent crisis of salmon farming in Chile is the typical example of the above. This industry experienced exponential growth since the 1980s. Concomitantly with the above, industrial structure and firm behavior changed drastically in direction to enhancing production volume and competitiveness in order to maximize profit.

In conventional models of firm and industrial behavior, economies of scale, ´technological deepening´ and a higher capital labour ratio would underlie a successful growth performance along the industry ´life cycle´. In fact, Chilean salmon farming industry quite clearly followed the evolving steps of said model of industrial behavior. In the course of just two decades, the industry became more complex both organizationally and technologically, capturing the benefits of economies of scale and staging a successful process of internationalization. The larger firms in the industry moved closer to the international technological frontier closing the gap with world leaders in salmon farming. Blinded by the overall climate of success and favorable international prices that surrounded their operation firms started to overexploit the CPR to produce higher volume to maximize short term profits. They remained myopic to the negative impact of the ´common pool´ they were all exploiting. This phenomenon, however, can be explained in the evolutionary theory of the firm, in which firms had achieved production competence but not capability to interact with the local natural environment, such as the use of CPR.

The firm as well as industry attained competence, through R&D expenditure, creation of institution such as association. The firms increased production volume and became top producer next to Norway; nevertheless, in Chilean salmon farms, collective and local institution to manage CPR did not appear. Existing literature in this sector suggest that as the industry and firms increase in its size, firms increasingly seek for profit and created difficult condition to nurture trust and social capital to allow collective action to take place(Vignolo et al, 2007).

The pattern of firm behavior so far described resulted from various institutional failures, which cumulatively facilitated the degradation of CPR. Regulations specific to aquaculture addressing the behavior of firms in managing CPR was largely absent and, when actually illustrated was badly enforced and had limited effect due to lack of manpower and political will. Government provided funding for R&D; however, these funds did not involve a national strategy leading to ensure either sustainability or creation of common knowledge to manage CPR. Furthermore, the trust relationship within the salmon cluster deteriorated as industry evolved into large global firms. The joint impact of three factors, (1) lack of shared local knowledge on CPR (local carrying capacity), (2) lack of adequate regulations and institutional arrangements to manage CPR (enforcing capacity), (3) lack of collective action to manage CPR; had eventually led firms to take myopic profit maximizing behavior that eventually led the industry into ‘tragedy’.

Nor the firms, neither the government were able to stop what can be regarded as an ‘expected tragedy’ which sooner or later was to occur. A new institutional arrangement with better understanding of local carrying capacity is urgently needed to strengthen the weak regulatory system and re-orient firms’ strategy into a different long term trajectory.

Natural resource based industries have become a new ´engine of growth´ in recent years for many resource rich developing countries. Unlike conventional manufacturing industries, natural resource based industries have particular biological and environmental conditions that are not fully incorporated into conventional models of firm behavior. As can be seen from this case, the Chilean salmon farming industry successfully attained production efficiency; however, lack of ´collective action´ and institutional arrangements to monitor and manage CPR eventually damaged long term sustainability of the industry.

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APPENDIX

Box 1 Estimate of loss due to ISA crisis 2000-2005

<u>Bases of calculation</u>

-accumulated mortality per year: increased 65% (from 15%-25%)

-days required for harvesting: increased 10% (from 487 to 543days)

-weight at harvesting: decreased by 8% (4.5 kg to 4.1kg)

-Kg of harvest for fix amount of smolts introduced: decreased by 19% (3.7 to 2.9)

<u>Direct loss (short term)</u>

-loss in fresh water phase: 2000/ smolt	US$ 50 million
-loss of biomass	
kg/smolt: 96000 tons less x current price of smolt, 2.4/kg	US$ 230 million
loss from less growth:	US$ 55million
-economic conversion factor: 12% higher	US$ 126million
total loss adding above:	
treatment cost:	US$ 52million
operational cost:	US$20million
processing cost:	US$ 44million
Total loss:	**US$ 550-600million**

Source: Dr. A.Johnson presented at the seminar of Skretting, November 2007 in Puerto Varas, Chile

Above is the a preliminary calculation of the cost of environmental degradation - note that this deterioration occurred before the impact of ISA – thereby only measuring the incidence of increased mortality, length of cultivation time, increased use of treatments and antibiotics, higher mortality in the freshwater phase, etc, would reach the figure of US$ 500 million in the period 2001-2007. This can be seen as an approximation to the opportunity cost of overexploiting the resource. This is an estimate based on careful reflection on actual costs, but it certainly highlights the importance of environmental sustainability as a condition *sine qua non* for an adequate industry performance.

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