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# Natural Resource Industries, 'Tragedy of the Commons' and the Case of Chilean Salmon Farming

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***Abstract***: Chilean salmon farming has been considered as an outstanding example of success after growing at double digit rates for more than twenty years. While the expansion was indeed dramatic, it came at the expense of severe sanitary and environmental deterioration. The outbreak in 2008 of the infectious salmon anaemia, a viral disease that kills salmon, but does not affect humans, has made this utterly clear. The overexploitation of the 'commons' upon which the industry has grown and the lack of an adequate regulatory mechanism to monitor adverse environmental effects contributed to this disaster, which now threatens the future of the industry and the country benefiting from its natural comparative advantage for salmon farming. The paper shows that activities based on the exploitation of a common pool resource require quite a different analytical approach than the one conventional neoclassical theory offers us for the understanding of firm and industry behaviour. This study shows that industries of this sort enjoy unique location-specific conditions requiring specific know how, R&D, and strong public-private cooperation in order to attain environmentally sustainable long term growth.

***Keywords***: Chilean salmon farming, common pool resources, natural resource based industry, 'tragedy of the commons'

***JEL classifications***: D01, L22, Q22, Q57

## 1. Introduction

The Chilean salmon farming industry experienced a dramatic downturn since 2008 with rapid spread of the Infectious Salmon Anaemia (ISA), a viral disease that affects the salmon's immune system, eventually leading to death. With the benefit of hindsight we now know that the long term decay in industry performance has been the outcome of a complex process of gradual productivity deterioration that started in the midst of a hike in world prices for salmon, inducing an increase in fish density in the cultivation ponds and a subsequent fall in the quality of water and in fish welfare. The reason for this is typical of an individual firm's seeking profit maximization, associated with increasing fish density in the cultivation tanks triggering industry failure as a result of overexploitation of the 'common'. An abnormally high fish density in the cultivation tanks favours the horizontal transmission of pathogens and vectors, which operates freely in the waters and this facilitates the diffusion of viral diseases. This situation suggests a typical 'tragedy of the commons' scenario, closely resembling the one described by Hardin (1968).

The purpose of this paper is to examine the economic and institutional circumstances that caused the systemic collapse in salmon farming in Chile by focusing both on firm, as well as on industry behaviour. Salmon farming depends on a highly particular and country-specific set of biological and environmental forces that demand location-specific knowledge and understanding, together with a set of institutions capable of governing the 'common'. It is important to notice that neoclassical production theory is helpful in explaining firm behaviour under more conventional circumstances, but it is next to useless in the case of activities like this one in which biological and environmental forces of an unknown nature introduce a significant degree of uncertainty and demand adaptive change in production organization. Neoclassical microeconomics is based upon the robot-like behaviour of a single 'representative firm' that optimizes future earnings under the constraint of a given set of exogenous parameters, perfectly understood and discounted by the entrepreneur. Little attention is paid in such a theoretical environment to the local carrying capacity and to the institutions conditioning firm and industry behaviour addressing the protection of the commons.

In other words, salmon production – and aquaculture in general – belong in a conceptual and analytical sphere in which models of firm behaviour need to encompass the highly uncertain and probabilistic nature of the production conditions in which firms operate. Indeed, salmon farming and aquaculture appear much closer to the inductive and open research agenda advanced by contemporary evolutionary economics (Nelson and Winter, 2002) and the political economy approach of common pool resources (Ostrom, 1990). If we are to understand firm and industry behaviour under such circumstances, many new questions of an organizational and institutional nature need to be brought to the fore and location-specific research needs to be undertaken if production is to be done under long term environmentally sustainable conditions.

The paper is structured in four sections. Section two presents theoretical considerations from the extant literature on natural resource based industries, economic governance scenarios where common pool resources (CPR) prevail and the contributions of evolutionary economics. Section three describes the behaviour of Chilean salmon farming companies paying special attention to the country-specific forces that have affected the long term behaviour of firms and institutions. In this section we present empirical evidence collected during the course of a field study carried out in mid-2009. Finally, we summarize the conclusions of our research and advance a few policy suggestions.

## 2. Theoretical Considerations

Three different bodies of literature bearing on the study of salmon farming are briefly reviewed in this section. We begin by briefly mentioning the early literature on natural resources as an impediment to growth, then examine governance issues and the role of institutions in ‘common pool’ based scenarios and finally we look at evolutionary theorizing on the behaviour of firms in CPRs. Shortcomings of dominant mainstream views are pointed out in all three cases.

### *2.1 Natural Resource Based Industries and Developing Countries*

Early development economists looked at natural resources as an impediment to growth, pointing out the long term decay in terms of trade of the natural resource exporting countries and to the capturing of the benefits of productivity growth and technological progress in the primary sector of the economy by the consumers of more developed, industrial nations (Prebisch, 1950; Singer, 1950; Sachs and Warner, 1995, 1997, 1999). However, under the impact of recent rapid advances 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 become a strong ‘engine for growth’ as they have a high potential for the incorporation of new knowledge coming from the biological and environmental sciences (de Ferranti *et al.*, 2002; ECLAC, 2004). 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 Ferranti *et al.*, 2002, von Tunzelmann and Acha, 2005). However, the success of such industries often requires careful attention to be given to local knowledge generation activities and environmental specificities. Katz (2004) has made this point arguing that these activities demand country-specific knowledge generation efforts if they are to operate efficiently. He argues that domestic companies cannot rely entirely on imported know how and foreign technological blue prints if they are correctly to manage local production conditions.

It is important to understand that natural resource-based industries often operate on the basis of common pool resources (CPR), as is the case with salmon farming. The economics and governance of CPR-based sectors identifies a major research agenda to which we now turn.

### 2.2 Management of CPR

The management of CPR[1] generates an inner tension between individual users of the common and their profit maximizing behaviour, and a group of users (in this case, narrowly defined as an industry) and its collective performance. As each individual firm attempts to maximize its private use of the 'common' it eventually inflicts welfare losses to the rest of the group by depriving others from access (Feeny *et al*., 1990; Ostrom *et al*., 1999). Hardin (1968)[2] had presented a simple model of 'herder' behaviour. By putting one more cow in a limited space of land (common), the individual's maximization attempt – through the eventual overloading of the resource – would cause a reduction in the collective benefits to all users of the common. He addressed 'the tragedy of the commons' by emphasizing the possibility of two different governance models of CPR, *viz*., one, government regulation (role of state) and two, exclusive private property ownership and the role of the market.

However, Ostrom (1990) considered 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 using 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 to restrict access and create incentives for users to collectively 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*. To support sustainability,[3] they have to act collectively for common purposes (Ostrom, 1990).

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

Others note that the idea of finding a general blueprint for successful CPR management is 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, the rules that work well to facilitate collective action in one case may not work well in other cases" (Poteete and Ostrom, 2004: 454). They argue that the 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, emphasize that successful management requires *local specific institutions, 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 structures. 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. Holling *et al.* (1998) 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" (Holling *et al.*, 1998: 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 further state that sustainable economic activities involving CPR need institutions that link the environmental with socioeconomic 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 intervention and regulation to induce behavioural change and collective action among stakeholders. For such collective action to emerge, the presence of trust and social capital among the stakeholders are considered crucial (Coleman, 1988).

The management of CPR also requires an understanding of local carrying capacity. The carrying capacity is generally discussed from four different angles of demography, economics, ecology and epistemology (see McMichael *et al.*, 2003). Locating within the local context, allows the integration of the four different dimensions of carrying capacities coherently for understanding the 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 the Firm*

Evolutionary economics looks at the process of economic transformations of firms, industry organization and institution paying attention to the role played by diverse agents based on their experience, and interaction among them.

Evolutionary economics differs from neo-classical economics in various ways, but fundamentally in its 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 (1982) looked at the changes in technology and routines as firms go though processes of selection, increase in variety and establish routines. The market has an important role in selecting successful firms that 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 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. Evolutionary economics views the process of firms' survival as dependent on how effectively firms can learn and unlearn the routines as they co-evolve with the market. Neoclassical economics assumes that there is universal rationality and information symmetry in learning processes while evolutionary economics casts doubt over such a proposition as firms' rationality is 'bounded' and complex due to different forms of production organizations (see Lall, 1992; Nelson, 2008; Rasiah, 2009).

There is an important distinction between competence and capability with regards to firms' ability to change (Nelson and Winter, 2002; von Tunzelmann and Wang, 2007; von Tunzelmann, 2009). Although Nelson and Winter (2002) do not make a clear distinction between competence and capability they state, however, that competence is "achievable when skills and routines can be learned and perfected through practice" (Nelson and Winter, 2002: 29). From the evolutionary point of view then, importance is placed on how firms can handle contrasting demands from different types of situations through learning processes. Von Tunzelmann (2009: 446) makes more explicit comparison where he considers that capabilities are "directly involved in transformations", while competencies are "previously transformed and are hired or otherwise bought in to assist in the ensuing process". He sees capability as more closely associated with 'dynamic capability' (Teece *et al.*, 2000) that enables firms to transform in co-evolutionary fashion.

Similarly, with reference to firm related activities, Katz (1987) makes a distinction between different sorts of capabilities being developed by firms *pari passu* with production. Firms first develop operational capabilities and much further in time new product and new process design capabilities. Innovation capabilities come last, when firms have already learnt a great deal about the state of the art. Viotti (2002) in an attempt to establish a framework for understanding technological change through a comparative study of South Korea and Brazil, distinguishes between production capability, improvement capability and innovation capability in his study of 'National learning system'. He identifies both 'active' and 'passive' learning in the technology absorption pattern and considers that active learning enables innovation and is compatible with 'Schumpeterian development'. As shown above, various attempts were made to distinguish the ability of firms to perform efficiently from that other set of capabilities that enables them to change and adapt to an ever-evolving environment.

Much of the discussion so far on evolutionary economics is largely based upon the study of manufacturing industries in which firms' capacity to interact with the market and co-evolve with it is the most important factor. This literature makes almost no mention of environmental sustainability. Neither does it discuss at great length, management of CPR which may (in case of natural resource based industries) have a large role in conditioning production outcomes and firms' activities and strong influence on the trajectories of technological development. This is in contrast to the literature on management of CPR which recently started to look at more holistic interactions between 'ecology and the rest' in a systemic way, but much in this area remains in the black box. In the industries based on natural resources, sustainability of CPR plays a crucial role in determining the 'survival' of firms as well as of the industry. However the evolutional theory of firms do not seem to have paid enough attention to the sustainability aspect of natural resource based industries, since most case studies are concentrated on manufacturing activities. Industries based on natural resources may therefore constitute a topic worth exploring as co-evolution must take place among market, CPR and technology to establish sustainable long term capabilities.

Recent literature indicates that natural resource based industries can be an 'engine for growth' in developing countries. However, such an 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 users (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 to global markets, science, technology and more. Identification of local carrying capacity is a complex task of finding equilibrium between ecology and human behaviour. The power to enforce strict regulatory rules and the ways in which these are enforced have an important role in determining such a co-evolutionary process. The presence of trust and social norms (social capital) is considered essential for the management of CPR to draw upon collective action. The evolutionary theory of firms, unlike the neoclassical one, emphasizes the importance of co-evolving nature of market, technology, and firms in transforming routines. It presents a useful framework for understanding transformation of firms and industries, but demands further consideration of the additional circumstances associated with CPR management.

## 3. Chilean Salmon Industry

Chilean salmon farming provides a dramatic story of a non-native species being incepted in a highly receptive natural environment and later cultured to generate employment and rapid economic growth in poor coastal regions of Southern Chile. Both the genetic material and the production technology for salmon farming were originally imported from abroad and subsequently adapted to local environmental conditions. While local climatic and geographical factors were central to successful salmon cultivation, the sanitary crisis to emerge later on, demonstrates a lack of adequate 'social technologies' and institutions required for environmentally sustainable long term exploitation of the underlying natural comparative advantage. We discuss in this section the impact of this lack of domestic capabilities and the subsequent sanitary and environmental crisis resulting from such lack of local technological capabilities.

### *3.1 Chilean Salmon Farming and the Recent Sanitary Crisis*

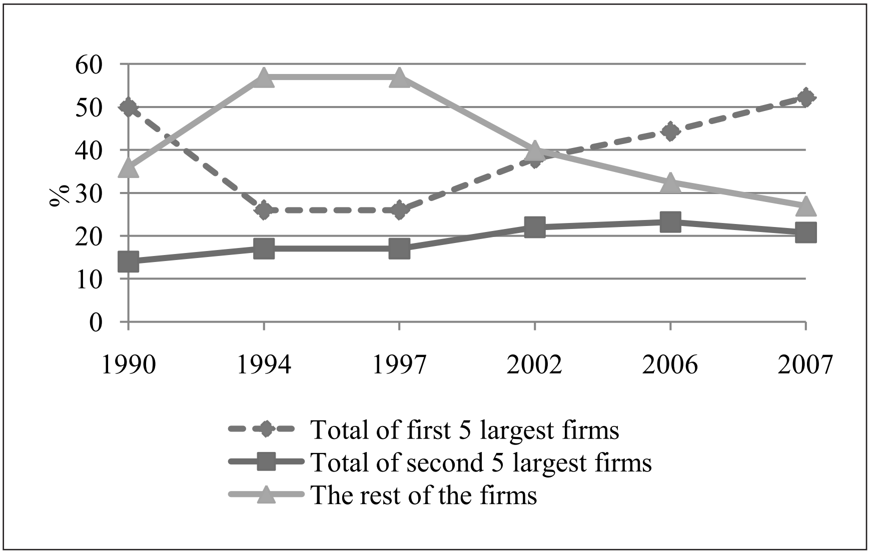
Most studies on the Chilean salmon farming industry highlight two major facts. On the one hand, the important role the Chilean public sector played in the original inception of the industry and, on the other hand, the major role learning by doing and technological adaptation efforts had on its growth during the initial stages of industry expansion (see 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 on examining the recent sanitary and environmental crisis in order to illustrate the extent to which the lack of understanding about management of CPR underlies much of what has happened within Chilean salmon farming.

#### *Demography of Firms before the Crisis*

By the early 2000s salmon farming in Chile had reached the status of a mature oligopoly in which five firms produced more than 50 per cent 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. First there were 'traditional firms' established during the initial years of industry inception in the 1980s followed by '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 are 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 entries might have resulted in the erosion of intra-industry trust and cooperative efforts – social capital – *vis-à-vis* the early period of industry inception in the 1980s. According to this view, the increasing diversity in

Figure 1: Export Share by Size of Firms



Source: Based on Bjondal and Aarland (1999) and AquaChile (2003, 2007, 2008).

Table 1: New Firms Entering the Salmon Industry since mid-2000s

| Firms | Activities | Year entered aquaculture | Investments (e) Millions of US$ | Productions thousand tons | Area of operation | Other activities | Origin | Note |
|---|---|---|---|---|---|---|---|---|
| Salmones El Golfo | cultivation centre | 2005 | 80 | 20 | XI | mussls / extractive fishery | Chile | Group Yaconi - Santa Cruz of Pesquera El Golf |
| Salmones Humboldt | cultivation centre | 2006 | 70 | 20 | X | mussls | Chile | Pesquera Coloso with group of business man |
| Salmones Itata | cultivation centre | 2006 | 60 | 30 | XI | mussls / extractive fishery | Chile | controlled by Sarquis family |
| Salmones Cupquelan | cultivation centre | 2004/2008 | 80 | 40 | XI |  | Iceland / Canada | Icelandic holding controlled Robert Gudfinnsson the changed the owner to Cooke Aquaculture, Inc |
| Salmones Aysen | cultivation centre | 2007 | 15 | 25 | XI |  | Chile / USA | Icicle Seafoods y Pablo Barahona, of ex executive of Salmones Tecmar |
| Provi. Fish Farms | cultivation centre | 2006 | 5 | 3 | XI | extractive fishery | Chile | Pesquera Landes |
| River Fish | cultivation centre | 2007 | 50 | 18 | XII |  | Chile | Algeciras S A owned by Eduardo Elberg |
| Tornegaleones | cultivation centre |  | 25 | 20 | XII |  | Chile | Eblen group |
| Food Corp S. A/ Pacific Seafood | cultivation centre | 2008 |  |  | XI |  | Norway | Leroy Group |
| Acuimag SA | fresh water phase centre egg, smolts | 2007 |  | …. | XII |  | Chile | Galmez family former owner of Almacenes Paris acquired 80% of company |
| Total |  |  | 385 | 176 |  |  |  |  |

Source: Based on AquaChile, Revista Aqua March 2007, and March 2008.

stakeholder composition might have negatively affected collective action aiming at protecting the 'common' (Ostrom, 1990).

### *Magnitude of the Crisis*

The industry suffered a dramatic downturn at the beginning of 2008 as the ISA spread with a devastating effect. The impact of the crisis was not limited to salmon farming firms alone as it rapidly reached the intermediate input and production services suppliers. Close to 20 thousand jobs were lost in the short period of two years since and numerous coastal villages whose socioeconomic functioning depended entirely on the demand for skilled and unskilled labour by salmon farming companies were thrown into social disarray.

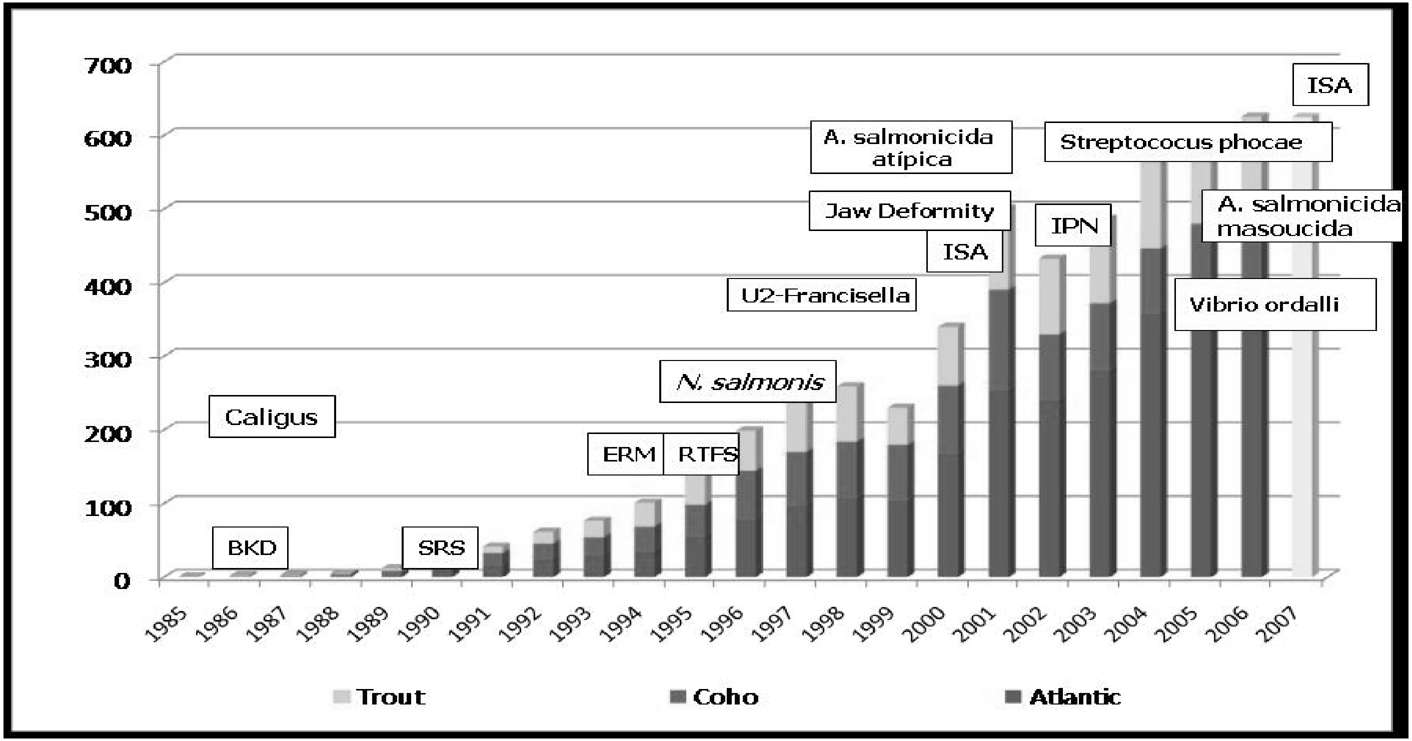
By 2010, the production of salmon had fallen to around 200 thousand tons down from its peak of nearly 700 thousand tons in 2006. By 2009 close to 60 per cent of the cultivation centres were out of production. What started as a sanitary and environmental crisis very soon developed into a financial crisis as many firms simply could not service their loans from 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 quickly refusing to extend their credit facilities to finance new cultivations as the uncertainty began to proliferate. Under such circumstances a significant process of 'de-clustering' emerged, with production service suppliers – e.g. veterinarians, divers, net repair personnel, feed-meal manufacturers and feeders – moving out of the region in search of new job opportunities. *El Mercurio*, which is the largest Chilean newspaper, estimated that the standing debt of the industry with the banking sector came close to US$2 billion by 2009, which accounted for nearly one year's worth of exports.

### *Direct Cause of the Crisis*

It is commonly believed that the ISA virus was the source of the crisis apparently originating from Norway and arriving in Chile through 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 some time until certain environmental conditions – high density of fish in cultivation tanks, for example – induced its mutation and rapid spread (Bustos, 2008; Nieto, 2009).

The evidence suggests that decaying sanitary conditions started even before the ISA actually became epidemic. During the initial years of inception, i.e. 1980-1989, very few episodes of disease were reported. The industry grew

Figure 2: Diffusion of Pathogen and Production Volume



Source: 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: Bustos (2008).

rapidly during the 1990s to reach 200 thousand tons per annum by the end of that decade. *Pari passu* with the expansion of production the diffusion of pathogens became more noticeable. An independent survey of the sanitary situation carried out in the mid-1990s by local veterinarians confirms that the sanitary situation was worsening even before the ISA crisis had started (Bustos, 2008; Johnson, 2007; Nieto, 2009).

The local biologists and veterinarians we interviewed during the course of our fieldwork referred to the 'ecological triad of illness' as the interaction between the host (fish), the environment and the various pathogens acting in the environment.[5] 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 should not induce us to believe that other sanitary and environmental problems were not present even before the outbreak of ISA affecting the functioning of the industry, its long-term productivity and sustainability. In other words the crisis should not be seen as a consequence of ISA, but rather as the cumulative result of sanitary and environmental mismanagement which has been present and worsening for a number of years before the outbreak of ISA.

### *3.2 Micro-evidence of Crisis*

Salmon farming is highly conditioned by biological and environmental factors that affect fish well-being in cultivation ponds and introduce a great deal of uncertainty both in individual firm production activities as well as in industry behaviour. Microeconomic behaviour needs to be closely coordinated with biological and environmental variables which are very imperfectly understood by firms. More research concerning local environmental conditions is required to ensure that the various actors in the ecology of salmon farming operate in a coordinated way. This sub-section explains why the standard neoclassical lens is highly inappropriate for such an understanding.

#### *Economics of Salmon Farming*

Cultivating salmon (a carnivorous fish) in captivity involves a set of complex processes. 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 requires location-specific knowledge and cannot be considered as standard and universal as economists sometimes 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. Typically, salmon is first bred in freshwater lakes. Once matured, they are transferred into the sea where they are then cultivated in semi-open enclosures until they are ready for harvesting. The latter takes close to 15 months depending on the species involved. The fish is ready when it reaches a certain weight (usually 3.5 kg on average). If a conventional cost/benefit calculation is applied, the timing for harvesting is reached when the marginal cost of maintaining the fish in the enclosure equals marginal revenue. The decision is made by 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 behaviour is determined by two quite different sets of forces. On the one hand, biological and genetic forces determine the growth rate of salmon. On the other hand, economic and financial ones determine optimal harvesting time.

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 a 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 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 upon 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 ‘rule of thumb’ through trial and error.

In other words, unlike manufacturing in which production routines can be assumed to be fairly stable and predictable across production campaigns, production cycles and processes in aquaculture are extremely variant as they are heavily dependent on uncertain environmental conditions. Salmon farming constitutes a typical production activity in which uncertainty and the volatile nature of biological and environmental conditions systematically affect production outcomes.

### *Firm Behaviour*

As mentioned earlier, the ISA crisis did not happen just because of the spread of the pathogen. It required certain conditions (health and welfare of fish in the ponds, 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 behaviour and underlying factors that led to the crisis.

### *Concentration of Cultivation*

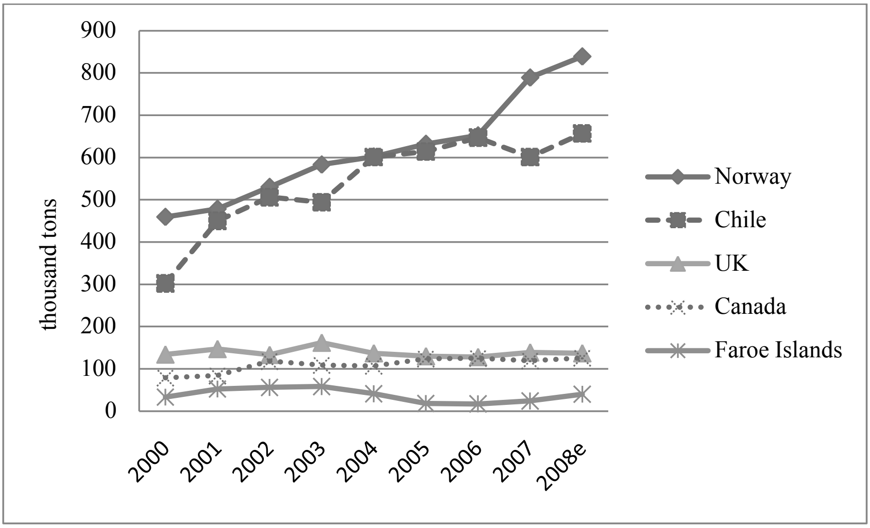
Currently, three quarters of the salmon farming concessions granted in Chile are located in a small territory covering no more than 300 km$^2$. The concentration of cultivation centres in Chile is striking when compared to

Norway, which has a total area of 1,700 km$^2$ for total cultivation area. Despite the limited areas of territories used for farming, there were no regulations monitoring distance between salmon farming centres (currently 2.27 km) until *Reglamento Ambiental para la Acuicultura* (RAMA) was enacted in 2001. As the result, cultivation centres in Chile are much more densely situated than in Norway.[6] The concentration of firms in a very small territory is also caused by several factors including: lack of physical infrastructure (such as road and port) connecting the cultivation centres to fish processing plants or to transport inputs (feeds, equipment, etc.); lack of human resources to work in the centres; and, a short supply of public services such as schools 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.

### *Increasing Fish Density*

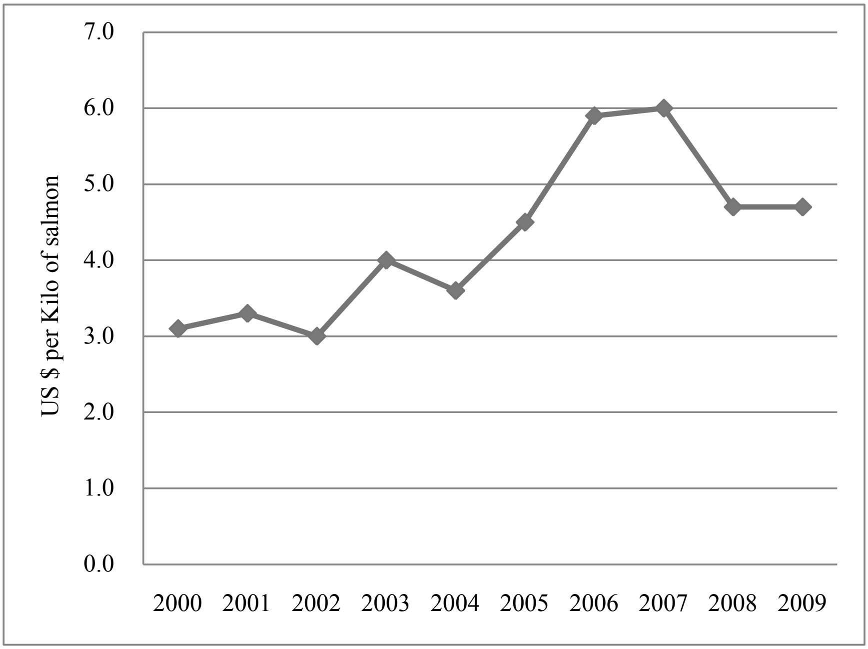
The production of salmon in Chile increased dramatically from 1999 onward. By 2006 it had reached an all time historical peak, at just about the same output level as Norway, the biggest exporter (see Figure 3) in the world. The strong incentive to increase production came from the rapid rise in world 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

Figure 3: Evolution of Chilean Export with Major Exporters



Source: SalmonChile (2009).

Figure 4: Fluctuation of Average Price of Salmon



Source: Compilied from AquaChile 2001-2010.

to approximately US$6 per kg in 2006 (see 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 beyond their biologically sustainable levels.

The evidence from Table 3 shows that the volume of fish per cultivation centre is much larger in Chile than in Norway (see Table 3). Data from EWOS, a salmon food company, effectively shows that the average number of fish per cultivation centre increased quite significantly (see Figure 5) since 2003 (EWOS Health, 2007). In other words, salmon farming companies behaved quite similarly to Hardin's herder mentality of increasing the volume of output from a given cultivation tank by adding 'one more fish' to a fix unit of space and resource. As the farming water is part of the CPR affecting other firms in the area, the horizontal transmission of vectors and pathogens had to be, *a priori*, expected.

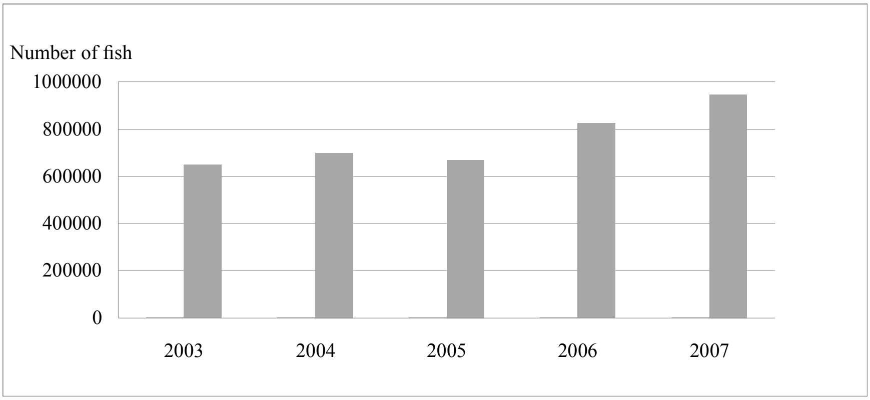
Once a given threshold of fish density in the pond is reached, increasing fish density will further worsen the 'environment' in which the biomass is reared. Data collected by EWOS Health (2007) provides circumstantial evidence of decreasing biological quality of the CPR, the 'water'. Table

Table 3: Average Salmon Weight per Cultivation Centre: Chile and Norway

| Chilean cultivation site | Average weight (tons/centre) |
|---|---|
| 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 Health (2007).

Figure 5: Average Number of Fish in each Cultivation Centre (Atlantic Salmon)



Source: EWOS Health (2007).

4 demonstrates the decreasing trend in productivity of firms in relation to 'water'. While the volume of salmon produced increased from 2003 onwards, other productivity indicators also show signs of deterioration. For example, the average weight per fish at the time of harvesting declined from 4.4 kg to 4.1 kg, the number of days required for harvesting expanded from 487 days to 543 days, and the weight of salmon produced (output) per unit of input (smolt or egg) decreased from 3.7 kg to 3.1 kg for the former and 1.3 kg to 1.1 kg for the latter. These figures indicate that the economic and biological rates of conversion[7] showed signs of deterioration, rising from 1.36 to 1.52 and from 1.24 to 1.34 respectively, i.e. more kilos of feed were needed to produce 1 kg of salmon. Furthermore, Figure 6 shows that the rate of fish mortality increased from 15 per cent in 2003 to 25 per cent in 2007. All of the above does not take into account the increase in expenditure incurred on vaccines and antibiotics required to prevent fish from getting ill, and the additional feed meal needed as a consequence of the extension of harvesting time.[8] In a nutshell, all economic and biological indicators point in one and the same direction, i.e. industrial productivity declining steadily from 2003 to 2007, even before the ISA disease started to spread in the midst of a hike in the price of salmon, and the production boom.

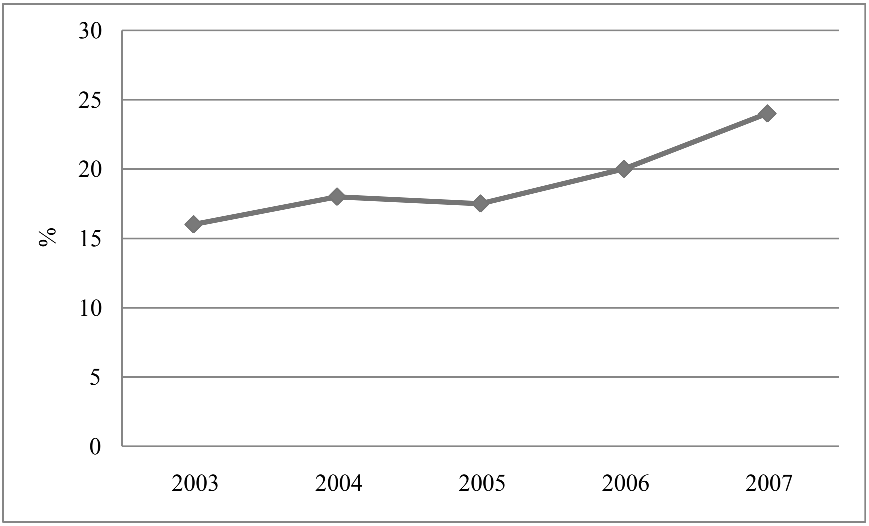
Hence, whereas export production soared from 2003 to 2006 and the sale of salmon increased, this was achieved concomitantly with a decrease in industry performance. Firms continued to increase production as world prices for salmon went up. Overall, the increase in the volume of production, even taking into account the loss of output due to higher mortality rate and

Table 4: Performance Indicator of Chilean 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 until harvesting | 487 | 497 | 484 | 488 | 543 |

Source: EWOS Health (2007).

Figure 6: Mortality Rate of Salmon



Source: EWOS Health (2007).

additional costs incurred to finance additional feed-meal and longer harvesting times, plus antibiotics and vaccines, still raised revenue because the marginal loss of productivity was valued less than the marginal gain from the increase in international price. In other words, the decision to put ‘one more fish in the pond’ was very much driven by rising world prices of salmon and in spite of the rising cost resulting from decaying local sustainability.

Furthermore, collective action also failed following a deterioration of trust and social norms (social capital) among firms (see Vignolo *et al*., 2007). Instead of taking collective action to secure a long term sustainable path, the firms opted for an opportunistic path of short term profit maximization. It is appropriate to notice the weakness of institutional arrangements monitoring access to CPR and the lack of incentive for users to do more research exploring optimal resource loading capacity.

Hence, the evidence is sufficient for 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 that were incorporated by salmon companies during the last decade, have been partially or totally destroyed by the fall in the marginal productivity of CPR. Each firm behaved rationally by trying to maximize profits in the context of given exogenous parameters, but with a collective outcome that resulted in the disregard of the CPR, thereby exposing the industry to the catastrophe.

### *3.3 Knowledge Acquisition and Organizational Routine*

One of the important ways to establish local knowledge is to invest in R&D. Another is to promote diffusion of knowledge among the stakeholders to create local specific technological capabilities. In the early days of Chilean salmon farming, 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 role of Fundacion Chile, a public-private sector organization (Fundacion Chile, 1989).

During the mid-1990s salmon firms became technologically more sophisticated, but they did so by importing capital goods such as computers, automatic processing technologies, scientific food formulae, to name a few. The technological gaps *vis-à-vis* the international 'state of the art' were gradually reduced at least as far as large local producers are concerned. But even the more successful firms in the industry did very little in terms of domestic R&D efforts. Chilean firms acquired 'competence' in the production of salmon, but they did not attain capability to deal with technological issues associated with environmental sustainability and biological and oceanographic forces impacting sanitary conditions.

Chilean R&D investment is quite low in general and it is particularly low in aquaculture when compared to Norway and Scotland. This does not mean that Chile completely ignored knowledge acquisition and creation. In fact, some efforts in promoting innovation and research were done by two public sector organizations that financed R&D. One is the National Commission for Scientific and Technological Research (CONICYT) which financed National Fund for Scientific and Technological Development (FONDECYT). The other is Chilean Economic Development Agency (CORFO) which did so with Fontec & InnovaChile.[9] Despite efforts made to promote innovation and research in this sector, innovation projects supported by CORFO have been focused on short term problem solving issues while the ones financed by the CONICYT were not fully utilized by the industry due to the lack of adequate university-industry linkages (OECD, 2007). In sum, salmon farming in Chile was capable of developing production competence in producing good quality output, but was not capable of obtaining long term capabilities for adequately developing country-specific know how and technology to secure the long term environmentally sustainable operation of the industry (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 was conducted to enhance productive technology, but did not address more fundamental basic research issues specific to the Chilean context such as to understand 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 bio-security, 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 pay attention to the specificity of local environmental conditions. This lack of attention to local sustainability is a prominent feature for catching up countries in aquaculture such as Chile, because most of the advanced countries[11] with long traditions in aquaculture have institutions that facilitate the management of CPR and promote domestic knowledge generation efforts adapted to local specific circumstances.

### *3.4 Regulatory Institutions*

Chilean aquaculture regulation has not been organized to effectively address improvements in firms’ sanitary and environmental practices. The first regulatory framework specific to aquaculture was enacted in 2000-2001. Due to the novel nature of the industry, private sector knowledge is always more advanced than that of the public regulatory body. Furthermore, the public sector has placed more emphasis on a developmental rather than a regulatory role to promote this new exporting industry, which is reflected in the fact that the National Fishery Service Agency (*Servicio Nacional de PESCA* – SERNAPESCA) did not have an independent regulatory body, resources and manpower to monitor firms for regulatory compliance until as recently as 2009. In short, the knowledge gap with which the public regulatory body has operated, the emphasis public officials have put on promoting exports and the lack of resources and political will to ensure compliance by firms to the existing environmental rules contributed to the environmental collapse of the industry.

## 4. Conclusions

Recent expansion of demand and rising world prices of natural resources has created a production boom for natural resource endowed countries. This paper sought to establish that in the absence of adequate institutional arrangements in accordance with the local carrying capacity, countries can lose valuable natural resources and face severe environmental disaster in exchange for short-term economic gains.

The recent crisis of salmon farming in Chile constitutes a clear example that shows neither firms nor government regulatory agencies being able to prevent ISA from reaching epidemic proportions. The industry experienced exponential growth for more than two decades and as a result of that attained world status as an efficient salmon provider. Industrial structure and firm behaviour significantly improved production volume and competitiveness to maximize profits.

In conventional neoclassical terms the Chilean salmon farming industry attained large economies of scale, 'technological deepening' and a higher capital labour ratio all of which account for a significant expansion in growth and productivity. The industry evolved along its 'life cycle' becoming a mature oligopoly. The larger firms in the industry moved closer to the international technological frontier, which helped them close the gap with world leaders in salmon farming. Blinded by the overall climate of success and rising international prices, the firms started to overexploit the CPR to raise unit production volume so as to maximize short term profits. In doing so they myopically neglected the long term sustainability of the common pool. If only the instruments of evolutionary economics had been used successfully here, a new set of institutions might have helped the agents and public sector organizations to understand the role of biological, sanitary and environmental forces and could have helped the effective strengthening of the long term exploitation of the common under sustainable conditions.

The firms increased production volume making Chile the top producer next to Norway. Nevertheless, collective and local institution to manage CPR did not develop *pari passu* with the above. Furthermore, firms did not understand that they needed to spend more on R&D activities in order to adequately manage local production conditions and the technological specificity of the domestic environment. The joint impact of a lack of local knowledge on the CPR (local carrying capacity) and of adequate and enforced regulations and institutional arrangements to manage the CPR, eventually developed in this new version of the tragedy of the commons. Neither the firms nor the government were able to stop what can, *a priori*, be expected to develop into a social failure to exploit in a sustainable way a rich national endowment of natural comparative advantages.

An important lesson that can be drawn from this case concerning industries dependent on the long term sustainability of the natural endowment in which they are based, demands a very strong interaction between the economics of industry growth and the evolution of associated institutions. This has become all the more important given the ascendance of natural resources in several developing countries as an engine of growth. Unlike conventional manufacturing industries, natural resource based industries require cognizance of local biological and environmental conditions that conventional models of firm behaviour do not demand. It can be seen that the lack of 'collective action' and institutional arrangements to monitor and manage CPR eventually damaged the long term sustainability of the industry.

## Appendix 1

Box 1: Estimate of Losses from ISA Crisis, 2000-2005

*Bases of calculation*

- accumulated mortality per year: increased 65% (from 15%-25%)
- days required for harvesting: increased 10% (from 487 to 543 days)
- weight at harvesting: decreased by 8% (4.5 kg to 4.1 kg)
- kg of harvest for fix amount of smolts introduced: decreased by 19% (3.7 to 2.9)

*Direct loss (short term)*

| | |
|---|---|
| – 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$55 million |
| – economic conversion factor: 12% higher | US$126 million |
| total loss adding above: | |
| treatment cost: | US$52 million |
| operational cost: | US$20 million |
| processing cost: | US$44 million |
| Total loss: | US$550-600 million |

Source: Johnson (2007).

Box 1 presents cost estimates of environmental degradation prior to the ISA crisis in 2008. The calculation shows an estimated total cost of US$550-US$600 million accounted for the direct costs between 2000-2005, excluding incurred and indirect costs registered during this period and afterwards. Hence, this provides an approximation of the opportunity cost of resource overexploitation. The estimates, which are based on a careful reflection on actual costs highlights the importance of environmental sustainability as an essential condition for adequate industry performance.

## Notes

1. Common pool resources (CPR) include those properties 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, ranges and forests.
2. A similar idea to this was already presented by Gordon in 1954 and Scott in 1955, or even earlier by Lloyd in the 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).
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).
5. The authors acknowledge valuable collaboration by local biologists and veterinarians interviewed during the course of their field work. Among many others, we are grateful to Dr. D. Nieto, Dr. P. Bustos, Dr. S. Bravo and Dr. C. Wurmann.
6. 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" (Pucchi, 2009).
7. Economic conversion rate is the rate at which 1 kg of feed converted into 1 kg of salmon in economic value terms. Biological conversion rate is in biological terms.
8. See Box 1 (Appendix 1) for more detailed estimate calculations for the loss.
9. The total expenditure incurred on aquaculture in1983-2005 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 basic research on local carrying capacity for instance.
11. For example, the 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 a 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 fishing 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).

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