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Property rights as a tool for economic growth and welfare

The case of the Icelandic quota system

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Faculty of Economics

June 2015

HÁSKÓLI ÍSLANDS

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Preface

This essay is a 12 ETCS final project for a BS degree in the Faculty of Economics, University of Iceland. The advisor for the thesis is Dr. Ragnar Árnason, professor in economics. I wish to thank him for useful comments during this work's progress: for encouraging independent and critical thinking. I also wish to thank my parents, Heimir Ásgeirsson and Freyja Theresa Ásgeirsson, who have stood by me throughout my studies. My mother also deserves extra credit for proofreading the essay together with Robyn Vilhjálmsson.

Abstract

The quota system, the economy, property rights, and growth – these topics have caused many to theorise, hypothesise, dissect and discuss. This essay encases an amalgam of the ideas of respected and well known economists. I reflect on and examine a number of pertinent ideas contained within their works. I discuss various aspects of the institutional structure of Iceland's economy and how the nation's prosperity and success have been affected by the changes in its institutional structure. I particularly focus on the marine sector and its development over the last 30 years and how it has affected the Icelandic economy.

In the main body of this essay I discuss growth theory and property right theory, which paves the way to propound on various ideas raised by North, Acemogle & Robison, Demsetz and Alchian. I put forward certain findings and show how property right theory, together with the marine sector help to explain the evolution of the Icelandic economy and the prosperity it has experienced since World War II.

In the latter part of the essay I focus on the economy of Iceland, and in particular, the marine sector and argue how the effects of the ITQs have implemented an upturn in the financial prosperity of the fish industry and in stronger fish stocks. I also argue how this upturn has had positive effects for the whole economy. It is questioned if the fisheries could have yielded more wealth and if a main reason for lower profit could have been caused by the extensive debate that has surrounded the fishing management act.

I end by including my reaction to these debates, and review how further development in responsible fishing can be achieved in an expanding market.

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1. Introduction

One of the fundamental attributes of economics is to explain economic structure and the essential way in which the market system works. This essay will take the reader on a journey through the neo-classical growth theory to property right theory, and how property rights effect the incentives of individuals. These shape the institutional structure of the economy, which are the basis of nations' prosperity and success.

The thesis will explain the evolution of the Icelandic economy from World War II and what has driven its "boom and bust" cycles. It explains how the fishery sector has been the basis of these cycles, and how a better defined property right structure in the fisheries, with the highly controversial fishery management act, reshaped not just the sector but the economic structure of the Icelandic economy. The controversial debate concerning the fishery management act is examined and how it has actually reduced the prosperity and success of the fisheries and thus with it the prosperity and success of the Icelandic economy and its people.

To try and answer these questions and shed light on them, neo-classical growth theory together with property right theory are used. Acemogle and Robison have argued that it is impractical and futile to implement new technologies in countries where property is not respected, where agreements are not honoured, or where infrastructure and institutions in the community do not support the introductions of new technology (2008, 2010 and 2012).

The same holds for all economic activity; if property rights are not respected and are not of high quality, economic activity will not be maximized, thus reducing the opportunity of its people for prosperity and success.

The thesis is structured as follows: chapter 2 examines neo-classical growth theory, and lays the ground work for growth to be clarified. Growth theory explains growth, in terms of capital and technology. Chapter 3 lays the foundations of property right theory and how they affect the incentives of individuals. Also, how secure property rights influence economic activity and resource allocation by promoting the accumulation of capital and the efficient division of labour. Chapter 4 brings these two theories together and shows how they influence each other (particularly how property rights affect economic growth and output).

The concept of property rights and how they shape economic activity is demonstrated in chapter 5. Thus, chapter 5 provides a case study on the effects that better defined property rights, in the form of ITQs, have reshaped the Icelandic economy. The chapter is divided into two sub-chapters. In 5.1 the evolution of the Icelandic economy is studied, focusing on the marine sector. 5.2 shows what effects the ITQs have had, and how they have actually turned an industry, which was averaging negative profits before its introduction, into one of the most prosperous industries in Iceland. Chapter 6 asks the question whether the debates concerning the fishery management act have actually reduced the prosperity of the Icelandic nation, i.e. could the ITQs have generated more wealth and if so, how much more? Chapter 7 is the final discussion and conclusion.

2. Growth theory

In the western world standards of living over the past few centuries have reached unimaginable levels. Why have standards of living improved so much? Why have countries accumulated so much wealth over the past few centuries? Economic growth theory can be a sound tool to study these issues. I will begin by reviewing the Solow growth model.[1]

The Solow model is a simple and convenient starting point to analyse growth. The Solow model has four variables; output *(Y)*, capital *(K)*, labour *(L)* and technology *(A)* (sometimes described as knowledge).[2] The economy has certain amounts of capital, labour, and technology at any given time and these three variables combined together produce output *(Y)*. The production function is described as:

$$Y(t) = F\big(K(t), A(t)L(t)\big) \qquad (2.1)$$

In the equation, *t* represents time (Romer 2012).

A critical assumption of the model is that the production function exhibits constant returns to scale in capital and labour. Hence, if we were to double the quantities of capital and labour, and hold technology *(A)* fixed, the quantity produced would be doubled. By these assumptions only more labour and/or capital is needed to add to the output of the economy. However, because of diminishing marginal product of labour and capital there are limits to how much additional labour and capital can contribute to the economy and maintain growth.

Increasing production does not necessarily mean the welfare of the nation increases. What will be more prosperous is to increase production per unit of labour, this should result in increasing welfare though it is not quite clear it will. One way to increase production per unit of labour and thus welfare is to increase the productivity of the labour. This can be done by increasing capital, i.e. giving labour more machinery, computers etc.

Notice in equation (2.1) that *A* and *L* enter multiplicatively, *AL* is referred to as *effective labour* (Romer, 2012). When technology enters the equation in this fashion it is known as labour-augmenting.[3] It is more convenient to work with the model when *A* enters in this form

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[1] The Solow model, sometimes known as the Solow-Swan model was developed by Robert Solow and T. W. Swan in 1956.

[2] The technology variable can also be thought of as describing all other variables that contribute to growth that are not described by labour or capital.

[3] If technological progress enters in the form: $Y(t) = F(A(t)K(t), L(t))$, it is called capital-augmenting and if it is entered in the form $Y(t) = A(t)F(K(t), L(t))$, it is called Hicks-neutral.

and easier to analyse the effects various variables have on the behaviour of the model. This condition also implies that the ratio of capital to output, *K/Y* will settle down, i.e. that the ratio is a constant.

Consider the assumption of constant returns to scale. It is convenient to think of it as two separate assumptions. The first supposition; the economy is large enough that the gains from specialization have all been exhausted, i.e. it is assumed that the economy is sufficiently large that additional inputs will be used essentially in the same way as existing inputs, and that output will increase in the same manner as inputs are increased. The second supposition is that other inputs, like land and natural resources are relatively unimportant.[4] Solow (1956) assumes that there are no scarce non-augmentable resources like land and natural resources. He says that scarce land would lead the model to exhibit decreasing return to scale in labour and capital. That would lead the model to become more Ricardian (Solow, 1956).

Constant return to scale allows us to rewrite equation (2.1) by dividing it by *1/AL* which yields:

$$\frac{Y}{AL} = F(\frac{K}{AL}, 1) \quad (2.2)$$

Y/AL is output per unit of effective labour and *K/AL* is the amount of capital per unit of effective labour. Let's define $k = K/AL$, $y = Y/AL$ and $f(k) = F(k,1)$. Now (2.2) can be written as: output per unit of effective labour as a function of capital per unit of effective labour.

$$y = f(k) \quad (2.3)$$

k and *y* are useful tools with which to learn about the variables that are being described, i.e. *K* and *L*. Furthermore, to analyse the model it is convenient to look at *k* and the behaviour of that variable instead of analysing *K* and *AL* directly.

The Solow model is set in continuous time. The model interests concern how labour, capital, and technology change over time. The outlined model assumes that labour and technology grow at a constant rate *n* and *g*.

The evolution of capital over time is defined as:

$$\dot{K}(t) = s \cdot Y(t) - \delta \cdot K(t) \quad (2.4)$$

Where s and δ represent savings and depreciation, respectively, and are constant and exogenous. Equation (2.4) assumes that a fraction of output is saved, i.e. invested in new capital

[4] There are growth theory models which describe the effects of natural resources and land, but they will not be examined in this thesis.

and that existing capital depreciates at the rate of δ.

Labour and technology are exogenous to the model, so if the economy is to be studied the behaviour of our third input, capital, must be analysed.[5] To look at the dynamic of k, the derivative with respect of time is taken, and with some algebra leads to the following result:

$$\dot{k}(t) = s \cdot f\big(k(t)\big) - (n + g + \delta) \cdot k(t) \tag{2.5}$$

Equation (2.5) is a key equation in the Solow model. The equation shows that the rate of change of capital stock per unit of effective labour is the difference between actual investment per unit of effective labour, $sf(k)$, and the break-even investment, $(n + g + \delta) \cdot k$, i.e. the amount of investment that must be done to keep k at a constant level.

The reason why investment is needed to prevent k from falling is twofold. Firstly, existing capital depreciates at the rate of δ. Secondly, the volume of effective labour is growing at the rate $n + g$ and thus capital stock must grow at the same level to hold k steady.

The conditions of the model are that the line that represent the first term in equation (2.5), $(s \cdot f\big(k(t)\big))$ will be steeper than the line that represents the second term, i.e. $((n + g + \delta) \cdot k(t))$. Thus, in equilibrium when condition $s \cdot f_k - (n + g + \delta) < 0$ is met, the model predicts that k converges to k* on a balanced growth path, i.e. that actual investment and break-even investment will be equal.[6] Labour and technology grow at a constant rate n and g and capital stock *K*, equals *ALk*, and since k will be constant at k*, *K* will grow at a rate $n + g$. Because the model exhibits constant return to scale, output *Y* will also grow at the same rate. Finally, capital per worker *K/L*, and output per worker *Y/L*, grow at rate g. Also, the model indicates that regardless of its starting point, the economy will converge to a balanced growth path, i.e. where each variable in the model is growing at a constant rate.

The parameters (s, δ, g, n) all have different impact on output. An increase in s will shift actual investment upward and raise k* but k will not immediately reach the new value of k*. Initially, k is equal to the old value of k* and at that level actual investment exceeds break-even investment, i.e. more resources are allocated to investment than are needed to hold k constant. k will begin to rise and will continue to rise until it reaches the new value of k* where it will remain constant. This is shown in figure 1.

[5] The analysis focuses on capital stock per unit of effective labour, *k*.

[6] *k** denotes the value of *k* where actual investment and break-even investment are equal.

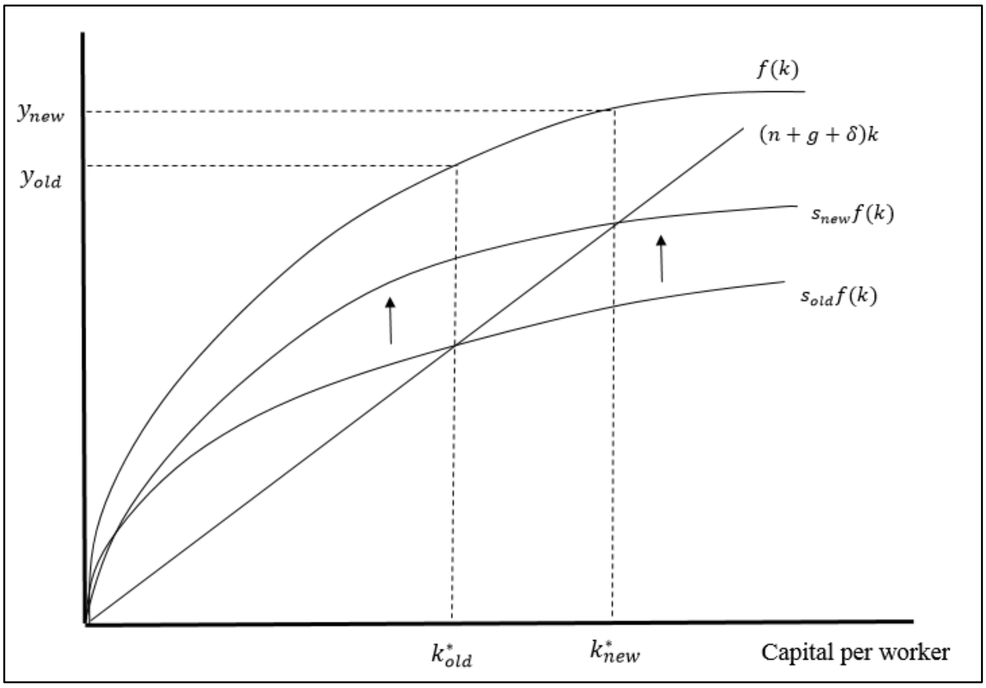

Figure 1. Effects of an increase in the saving rate.

The figure shows that during this period the economy will experience economic growth, i.e. when k is catching up with k* but after it has caught up, the growth will halt. Thus, a permanent increase in the saving rate, *s*, will only produce a temporary increase in capital per worker. This is because the growth rate will exceed g when k is rising. Hence, when k has reached its new level k^*_{new}, the growth rate of *Y/L* will return to g. In sum, when the saving rate changes and more capital is accumulated, it will only have a level effect not a growth effect, i.e. it changes the economy´s balanced growth. Output and capital per worker reach a new level, but in the new equilibrium they stay constant.

A similar story holds for the parameters (δ, n). An increase in them will have the reversed affect that the savings rate has, i.e. an increases in population in excess of the other parameters implies that output per worker will decline and thus welfare. The same can be said if capital deteriorates faster than new capital is invested, thus leading to capital per worker to fall. These effects can be thought of as the straight line in figure 1 becoming steeper.

These results imply that when the economy is on a balanced growth path, it will solely achieve long term growth by increasing the rate of technological progress. All other changes have only level effects.

2.1 Growth accounting and human capital

Often we are interested in the determinants of growth, i.e. we want to know what factors of production are contributing to growth over a period of time and what stems from other forces.

One way to tackle this subject is to use growth accounting, which was conceived and innovated by Abramovitz (1956) and Solow (1957). Consider the production function (2.1), $Y(t) = F(K(t), A(t)L(t))$ and take the derivative with respect to time:

$$\dot{Y}(t) = \frac{\delta Y(t)}{\delta K(t)} \cdot \dot{K}(t) + \frac{\delta Y(t)}{\delta L(t)} \cdot \dot{L}(t) + \frac{\delta Y(t)}{\delta A(t)} \cdot \dot{A}(t) \qquad (2.6)$$

Economic growth can been found by dividing both sides by *Y(t)* and multiplying the terms on the right hand side by *K(t)/K(t)*, *L(t)/L(t)* and *A(t)/A(t)*, respectively.

$$\frac{\dot{Y}(t)}{Y(t)} = \alpha_K(t) \cdot \frac{\dot{K}(t)}{K(t)} + \alpha_L(t) \cdot \frac{\dot{L}(t)}{L(t)} + R(t) \qquad (2.7)$$

Here, $\alpha_K(t)$ and $\alpha_L(t)$ represent the elasticity of output with respect to capital and labour at time t.[7] Equation (2.7) provides a way to break down the growth of output into the contribution of capital and labour and the remaining term *R(t)* known as the Solow residual.[8] The Solow residual is interpreted as a measure of the contribution of technological progress, as was mentioned earlier, everything that contributes to growth other than the contributions of capital and labour. Equation (2.7) can then provide information on whether the economy has sustained growth over a period of some time because of more accumulation of factors of production, or gained efficiency from technological progress.

Efficiency gains can also stem from factors such as skills that individuals are endowed with, or acquired skills, i.e. skills that individuals learn from experience and acquire from education. From the above information it can be seen that a new variable can be introduced to the growth model: *Human capital (H(t)). H* is the total amount of service supplied by workers, i.e. the total contribution of workers with different skill levels. The model assumes that human capital depends only on the years of education that workers acquire. Human capital can be defined as:

$$H(t) = L(t) \cdot G(E) \qquad (2.8)$$

Where *L* stands for labour and the $G(\cdot)$ is a function giving human capital per worker years of education (Romer, 2012). This information now enables the rewriting of production function (2.1) with a new variable. To facilitate the analyse it is convenient to assume the production function in a Cobb-Douglas form including human capital:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta} \qquad 0 < \alpha + \beta < 1 \qquad (2.9)$$

[7] $\alpha_K(t) \equiv \frac{K(t)}{Y(t)} \cdot \frac{\delta Y(t)}{\delta K(t)}$ and $\alpha_L(t) \equiv \frac{L(t)}{Y(t)} \cdot \frac{\delta Y(t)}{\delta L(t)}$

[8] $R(t) = \frac{A(t)}{Y(t)} \frac{\delta Y(t)}{\delta A(t)} \frac{\dot{A}(t)}{A(t)}$

The assumption that $\alpha + \beta < 1$ implies that there are decreasing returns to capital, this is because, if there are constant returns to scale, then there is no steady state for this model. The progress of the economy is determined by:

$$\dot{k}(t) = s_k \cdot y(t) - (n + g + \delta) \cdot k(t) \qquad (2.10)$$

$$\dot{h}(t) = s_h . y(t) - (n + g + \delta) \cdot h(t) \qquad (2.11)$$

Where *y* and *k* are determined as before and *h* = *H/AL*, s_k and s_h are the fractions of income invested in physical and human capital. In addition, the model assumes that human capital depreciates at the same rate as physical capital, *k.* The steady state of human- and physical capital are defined from equations (2.10) and (2.11). Substituting the steady state variables in production function (2.9) and taking logs and dividing the equation with *L(t)* will yield an equation for income per capita:[9]

$$ln\left[\frac{Y(t)}{L(t)}\right] = lnA(o) + gt - \frac{\alpha+\beta}{1-\alpha-\beta} \cdot \ln(n + g + \delta) + \frac{\alpha}{1-\alpha-\beta} \cdot \ln(s_k) + \frac{\beta}{1-\alpha-\beta} \cdot \ln(s_h) \qquad (2.12)$$

This equation shows how income per capita depends on population growth and on the accumulation of both physical and human capital. Equation (2.12) shows that the presence of human capital will lead to higher steady state savings in capital than in the absence of human capital, this is because even if $\ln(s_h)$ is independent of the right-hand side variables the coefficient on $\ln(s_k)$ will be greater.[10] Because higher savings lead to higher income, the higher income will lead to a higher steady state level of human capital, this happens even in the absence of unchanged percentage of income devoted to human capital accumulation. So the efficiency gains from acquired skills will increase the impact of physical capital accumulation on income (Mankiw, Romer and Weil, 1992).

Again, growth accounting can be used to see how different factors contribute to growth. Thus equation (2.7) can be changed to involve human capital:

$$\frac{\dot{Y}(t)}{Y(t)} = \alpha_K(t) \cdot \frac{\dot{K}(t)}{K(t)} + \alpha_L(t) \cdot \frac{\dot{L}(t)}{L(t)} + \alpha_h(t) \cdot \frac{\dot{H}(t)}{H(t)} + R(t) \qquad (2.13)$$

Where $\alpha_h(t)$ represent the elasticity of output with respect to human capital.

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[9] As this is not an essay on economic growth theory, derivation on equation (2.12), or as a matter of fact any of the equations in this chapter, are not needed. The concern lies only in the interpretation of them and the story they say.

[10] For example if $\alpha = \beta = 1/3$ the coefficient on $\ln(s_k)$ will be 1. Which is more than in the case where human capital is not included, i.e. $\frac{\alpha}{(1-\alpha)} < \frac{\alpha}{(1-\alpha-\beta)}$

Equation (2.13) is able to describe growth fairly well. Research has shown that the behaviour of most of the major industrialized economies in the past century are generally described reasonably well by the balanced growth path of the Solow model. The growth rate of labour, capital and output has been approximately constant. The capital-output ratio has been roughly constant and has been larger than the growth rate of labour. These facts are often taken as evidence that the Solow model describes the growth path of economies quite well (Romer, 2012).

The model gives limited guidance on why standards of living have improved so much, or why the world has seen such rapid economic growth in the past century. Growth accounting like equations (2.7) and (2.13), only examine the determinants of growth, for example, how much factor accumulation or improvements in the quality of inputs contribute to growth, while it ignores land and natural resources and the deeper issue of what causes the changes in these determinates and why the inputs are being used more efficiently. Later in this paper, it will be argued that increased quality of property rights are the main contributions to rapid growth and improved welfare. Property rights have positive impact on all four variables of the growth model as well as having direct impact on the production function by directing the factors of production toward where they are used most efficiently.

2.2 Where do we go from here?

The discussions above have just scratched the surface of the standard neo-classical growth theory. The above model examined, describes growth theory and what determines growth in some detail. The results of the model suggest the only thing that can determine long term growth and lead to higher standards of living is an increase of technology (A), all other variables can only have level effects or have negative effects on growth and welfare. The results though, only hold in equilibrium which can take a very long time to reach.[11] But (A) is exogenous to the model, i.e. the behaviour of the variable is taken as given, though it is the driving force of the model. As a result, only the difference in the effectiveness of labour can describe why vast accumulations of wealth have accrued in the past centuries and why the standards of living have improved so much. Furthermore, the model does not identify what is effectiveness of labour,

[11] An increase in saving rate will lead to more accumulation of capital and thus more capital per worker. On the path to equilibrium the economy will experience growth, but once in equilibrium the growth will halt. It can take a very long time to reach equilibrium, and thus the act of increasing capital can be enough to increase the standards of living.

thus difference in income can just as well be described by the difference in capital per worker.

The model cannot account for the vast difference in output per worker on the basis of the variation in capital per worker. To account for this variation the return on capital between countries would have to be enormous. However, there is no evidence of such enormous difference in rates of return, i.e. if capital contributions to output are reflected by its private return (Romer, 2012). Thus, we are back to the conclusion that the difference between countries can only be explained by the variation in technology. Hence, the difference could be explained by the difference in time and resources spent in research and development *(R&D)* and the accumulation of knowledge. The models fail to describe what can account for these differences. Likewise not described is why in some countries the labour force is more educated than in others and why some countries have easier access to physical capital than other countries.

To understand why the world has seen so much growth in the past centuries and why only some parts of the world have experienced these improvements in standards of living it is necessary to analyse the determinants of the stock of knowledge and capital over time, plus the incentives that determine the accumulation of these stocks. What determines how countries reach the balanced growth path, i.e. if it is the most desired path and how fast they can converge to equilibrium?

3. Property rights

In chapter 2 it was argued that in order to have long term economic growth, advances are needed in technological knowledge, *A*.[12] Nevertheless some parts of the world have not experienced the same economic growth as the western world, despite improvements in technology knowledge.[13] The Solow model assumes that at time *t*, all countries share the same technology *A*, and that in the long-run, regardless of their starting point, all countries will converge to the same per-capita income, *y*.[14] Thus, the model predicts that differences in income per capita must be caused by differences in capital-labour ratio, *k* (Eggertsson, 2011). As was pointed out in chapter 2.2, the variation between countries in *k*, cannot explain the difference in the performance of nations.

Technological progress is strictly dependent on the presence of adequate and appropriate social institutions in the community. These social institutions, unlike *A*, are local public goods. Social institutions represent formal rules such as law, social norms, beliefs and religion and the ability to enforce contracts and laws. Thus, *A*, is useless in an economy where social institutions and property rights are poorly developed. As Acemogle and Robison argue, it is impractical and futile to implement new technologies in countries where property is not respected, where agreements are not honoured, or where infrastructure and institutions in the community do not support the introductions of new technology (2008, 2010 and 2012).

In the previous few centuries the rise of the western world has become better-noted and discerned. Efficient organization is recognised as one of the keys to growth; it entails the establishment of institutional arrangements and property rights. These arrangements and rights create incentives for individuals which bring their private rate of return nearer to the social rate of return (North, 1976).[15]

This chapter will explain how property rights effect economic organizations and the effects

[12] Accumulation of capital was found to be sufficient in the short term.

[13] Economic growth has also varied between countries in the western world.

[14] So should we therefore throw away the Solow model and modify our assumptions that all countries share the same *A*? This will leave a problem. Neoclassical growth theory assumes that, *A*, is a pure public good that is available to all countries. We can recognize *A*, as having attributes of public good, i.e. it is non-excludable and non-rival, but is strongly dependent for its effect upon specific complementary goods (Eggertsson, 2011).

[15] Private rate of return is the total benefit that economic units receive from undertaking an activity. The social rate of return is the total benefit (positive or negative) that society gains from the same activity.

that these rights have on the incentives of individuals. Property rights explain why different societies have experienced different levels of innovations, education, capital accumulation, etc. Growth theory explains growth, in terms of capital and technology. However, it sheds little light on the causes of the accumulation of capital and adoption of technology and its adaptation to local conditions.

Secure property rights influence economic activity and resource allocation by promoting the accumulation of capital and the efficient division of labour mainly through five channels (Locke, 2013):

i. Each individual has incentives to take into account both the benefits and cost on society of his or her economic behaviour. In other words, property rights solve the problem of externalities.
ii. Motivation to increase investments as individuals and firms can expect to reap the benefits from their investments. This will lead firms and individuals to select the most productive investments, to determine what investment options are chosen. Insecure rights may lead firms and individuals to forfeit the fruits of their investments.
iii. Individuals will invest in themselves, i.e. education.[16] With ill-defined rights individuals have less incentive to invest in themselves because they will not expect to reap the benefits from the investment in education.
iv. Individuals will seek ever better ways of increasing production and the quality of production, with new and cheap ways, i.e. incentives for experiments increase. This happens because people will be able to enjoy the proceeds of the experiments, and the costs they incur if they fail. Restless attempts are the foundations of progress.
v. Firms and individuals will use their capital in the most efficient way. This will enhance the mobility of assets through transactions to others who are able to use capital in more efficient ways, while the owners of the assets will earn interest on them, thus increasing the efficiency of capital disposal. Further, formally defined property rights allow the disposal of property to be used as collateral, thus raising recourse for other financial actions (de Soto, 2000).

[16] This can be thought of as positive externalities because the individual alone does not reap the benefits, rather, the whole of society does.

Alchian (1967) has argued that in essence, economics is the study of property rights.

> "The allocation of scarce resources in a society is the assignment of rights to uses of resources… [and] the question of economics, or of how prices should be determined, is the question of how property rights should be defined and exchanged, and on what terms" (Alchian, 1967, p. 2-3).

The structure of property rights in societies can be understood as a set of economic and social contracts defining the position of individuals with respect to the utilizations of commodities and goods (Furubotn, 2005).

The definition of economic property rights can be understood on a much broader definition than just legal rights, which is one way to achieve property rights.[17] An economic property right is the "individual's ability, in expected terms, to consume the commodity (or the services of an asset) directly or to consume it indirectly through exchange" as argued by Barzel (1997, p. 1). Thus, property rights can be understood as the right to freely use a commodity, i.e. user rights that define potential use of the commodity, including the rights to transform, and even destroy it. In addition, the rights to earn income from the asset, and bargain user-rights for other individuals to use the commodity. And last but not least, the rights to transfer the rights of the commodity to another party, i.e. sell the asset (Eggertson, 1990).

The attributes of property rights, are subject to the character of the assets and the protection they achieve, this protection can be formal or informal (Barzel, 1997). Thus property rights, or the quality of them are forever changing because changes in knowledge will lead to changes in production methods, therefore changing the market value of the assets and incentives. When new techniques are learnt, i.e. doing new things or new ways of doing the same things, it invokes adverse and/or beneficial effects to which societies are not accustomed, i.e. these new techniques inflict externalities (Demsetz, 1967). Demsetz argued that "a primary function of property rights is that of guiding incentives to achieve a greater internalization of externalities. Every cost and benefit associated with social interdependencies is a potential externality".[18]

The concept of externalities can be understood: whenever individuals or parities have direct or indirect impact on a third party in ways that are not captured by the market price. For

[17] "Legal rights" is the term lawyer's use, and is enforced, in part, by the state. It can be loosely defined as a right under law to freely exercise a choice.

[18] It seems as though Demsetz misses the point that property rights also explain the efficient division of labour and the accumulation capital, i.e. that they define the incentives for the efficient use of labour and capital.

example, this can be when a firm's production process emits pollution. The emission of pollution imposes a cost on society that is not priced by the market, and thus not taken into account by producers. Externalities can also stem from whenever an individual decides to get into a car and enter the road, thus congesting it for other users and delaying them.[19] Therefore, the main attributes of an externality are where costs or benefits of production or consumption are directly imposed on a nonmarket actor. Externalities can thus be traced to a lack of a market when property rights do not exist or are insufficiently strong. To nullify the negative impact of externalities there needs to be a way to internalize the social costs individuals impose on others and establish a market that will evaluate the social cost (Nechyba, 2011).

This is where property rights come into play. They do not actually remove externalities. They just internalize them and thus make markets for them.[20] If, for the sake of argument, the externality was created by means of ”taking”, then the quantity available to other users will have been reduced. Property rights actually turn externalities into pecuniary externalities which are economically harmless. A pecuniary externality is harmless because the adjustment to it is optimal, and it can be traded. Thus through trade the interest of both parties is taken into account, i.e. only if one party values the resource more highly than the other can trade take place (Arnason, 1999).

Libecap has argued that property rights are the basis of every rational choice an individual takes. Thus, changes in property rights are the outcome of rational decision making where individuals are responding to new economic opportunities (Libecap, 1986). Libecap argued:

> "Property rights affect economic behaviour through incentives. They delineate decision-making authority over economic resources, determine time horizons, specify permitted asset uses, define transferability, and direct the assignment of net benefits. [Because] they define the costs and rewards of decision making, property rights establish the parameters under which decisions are made regarding resource use" (Libecap, 1986, p. 3).

In general, an owner has an incentive to attend to his property, to its expected or actual market value. Thus, the market value of a commodity and its allocation is controlled by supply and demand. Competition for ownership of assets between individuals will lead them to make use of society's scattered knowledge of the assets attributes, and thus each resource will go to

[19] This does not mean that all individuals are arrogant and mean people. Ordinary everyday people just do not think of the consequences and the effects of their actions, like for example, hopping in a car for a jaunt.

[20] They turn them into pecuniary externalities.

the particular owner who expects the asset to yield the highest benefit. Therefore, self-interest and utility maximization of individuals is the best supervisor of the world´s resources. The contribution of private ownership thus solves, in the most essential way, the economic problem of society, i.e. the utilization of the world scattered knowledge which is not given to anyone in totality (Hayek, 1945).[21]

Property rights are a human creation, as such they can often be limited by nature. Property rights are distributed to individuals by law and regulations etc. The general public does not always end up with all of them, and often these rights are imperfect because it is too costly to enforce them. As a result, individuals will make efforts to enforce property rights and establish them. These efforts have often be described as transactions costs.

In general, transaction costs have been defined as "the costs of running the economic system" (Arrow 1969, p. 48). Broadly speaking this can be interpreted as the costs of maintaining and establishing property rights, i.e. maintaining the market system. These costs include, the search for information about the distribution of price and quality of commodities, the search for potential buyers and sellers of commodities, making contracts, monitoring and enforcement of contractual partners, bargaining to find the true position of buyers and sellers when prices are endogenous and any commitment losses that will result from enforcing such efforts (Eggertsson, 1990).

In his ground breaking article, "*The problem of social cost*"(1960). Ronald Coase presents an interesting idea on the economic problem of externalities and transaction cost that stem from a lack of property right. In addition, he discusses what measures can be undertaken to eliminate these problems. Coase (1960) gives an example of a cattle-raiser and a crop-farmer. When the cattle-raiser herds his cattle he destroys land on which the crop farmer could have raised a crop. How do they solve this problem?

> "The amount which the farmer would pay for the use of land is equal to the difference between the value of the total production when the factors are employed on this land and the value of the additional product yielded in their next best use (which would be what the farmer would have to pay for factors)" (Coase, 1960, p. 6).

[21] The private net benefits and social net benefits are close to equal in this situation thus contributing to overall wealth of society.

If the damage exceeds the total amount the farmer would pay for the land, then it would be desirable to abandon the cultivation of the land and employ the factors of production elsewhere. In other words, as Coase succinctly explains:

> "Given the possibility of market transaction, a situation in which damage to crops exceeds the rent of the land would not endure. Whether the cattle-raiser pays the farmer to leave the land uncultivated or himself rents the land by paying the land-owner an amount slightly greater than the farmer would pay, the final result would be the same and would maximise the value of production" (Coase, 1960, p. 6).

Coase raises the question of whether the allocation of resources would be the same if the damaging party is not liable for the damage it causes. In this case, the crop-farmer could pay the cattle-raiser not to raise cattle if the marginal revenue would exceed the marginal costs incurred by both parties. To continue, Coase sums up:

> "It is necessary to know whether the damaging business is liable or not for the damage caused since without the establishment of this initial delimitation of rights there can be no market transactions to transfer and recombine them. But the ultimate result (which maximises the value of production) is independent of the legal position if the pricing system is assumed to work without cost" (Coase, 1960, p. 8).

This seems awfully simple, and an important feature of Coase´s essay is that this statement only holds when transaction costs are non-existent (and this is actually never true of the world in which we live). If there are transaction costs, Coase points out that the initial delimitation of legal rights has an effect on the efficiency of the economic system.

> "One arrangement of rights may bring about a greater value of production than any other. But unless this is the arrangement of rights established by the legal system, the costs of reaching the same result by altering and combining rights through the market may be so great that this optimal arrangement of rights, and greater value of production which it would bring, may never be achieved" (Coase, 1960, p. 16).

What Coase is highlighting are there can be barriers that keep individuals from getting together even after property rights have been defined, so that individuals can bargain their way out of externalities problems.[22]

Consider the Coase example, the transaction costs associated between the cattle-raiser and

[22] These barriers are transaction costs.

the crop-farmer would be, negating terms and agreeing to meet each other in the first place, making contracts etc. So even if property rights are well defined, they do not have all the rights associated with raising the cattle or growing a crop. But in a society where law and social infrastructure are strong, agreements will hold and transaction cost will be minimized. This will entitle the establishment of efficient property right regimes. Thus, economic decisions made in these circumstances will maximize the total wealth of the society, i.e. where all social benefits and costs are considered.

In the real world we encounter all types of property rights, these vary depending on transaction costs, and the nature of goods. These rights must be protected, and depending on the situation, these protection costs will differ. Thus, the property right regime that will be chosen over a commodity will depend on its attributes and how expensive it will be to gather information over these attributes. In other words, it will depend on transaction costs. Demsetz (1967) argued that a private property rights regime will only be established if the benefits from that regime exceed the costs from establishing such an ownership, i.e. the real value of the property right is strictly dependant on transaction costs. On the other hand, if the real value of the commodity is not enough that a private property right regime pays off, the commodity will not be protected and, therefore be in open access.[23] An important implication of Demsetz's theory is that the more valuable the real value of a commodity, the more valuable it will be to defend its title, leading goods to be in private property regime.

Often, many assets that are in common property regimes because they are too costly to protect, become private property through advances in technology. History is full of examples of such innovations. Take for example the invention of barbed wire, it enabled vast amounts of land to become enclosed and thus become private property, this also made livestock etc. that roamed the land more valuable.[24]

Different property rights regime will lead to different economic outcomes. The property right regimes that provide the most wealth are optimally and socially desirable. The assignment of

[23] Many commodities like fresh air, the open seas, and big open areas (like the great American plains of previous centuries) hold many attributes which are too costly to gather or protect and thus private property regimes for them don't pay off. Hence, these commodities become common property.

[24] For example, consider the situation of cattle husbandry, after the invention of barbed wire, it was cheaper to look after cattle, they did not inflict any harm on other properties (think of the Coase example), thus making the production process cheaper. Also, the cattle could no longer roam all over the place, thus gaining more weight and in the process becoming more valuable.

optimal property rights can lead to distributional effects. Accordingly, these polices will be controversial, they will lead to both political benefits, costs to politicians, and to those who are assigned these rights.[25] Those who receive "no positive affects" may protest the assignments, and demand compensation even though these assignments maximize social wealth. Agreements are always difficult concerning these matters because of asymmetric information. Side payments can be both theoretical and done in practise, but they are rarely a solution to these problems.[26]

Consequently, assigning property rights will always be a dilemma for politicians, and the resulting implications will often lead to solutions where the best regime is not necessarily chosen (Libecap, 1986). North (1976) has argued that the oppositions to new and better property right regimes in France and Spain was responsible, at least partially, for the slower economic growth there in the Middle Ages than in England and the Netherlands at the same time.

3.1 Property right regimes

Property right regimes differ depending on transactions costs etc. as was pointed out above. The most common property right regimes are private- or common property rights. The concept of private property can be understood to mean that an owner of property has full ownership title to the property. An owner can decide how to use his commodity, who may use it, what happens to the flow of income from the commodity, and the utility of the commodity. Common property regimes are complex. They involve rules and enforcement mechanisms that are often located in many different levels of administration that regulate exclusion and internal governance. When a common property title is well defined, a group of insiders control the use and management of the commodity. However, common property regimes do not give members of the group full titles of alienation or transferability, and thus members will not have full exclusive rights, as with the private property regime. Joint wealth maximization in groups like these will be a complex affair with unpredictable consequences, because each individual will strive to maximize his own wealth. Collective action problems could thus arise that will prevent joint maximization (Eggertsson, 2003). Figure 2 gives an example of both these regimes and their effects.

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[25] One does not need to look further than to Iceland, when they took up the ITQ system. This will be discussed later.

[26] Side payments can make new problems, like who should receive what, and what amount should be paid?

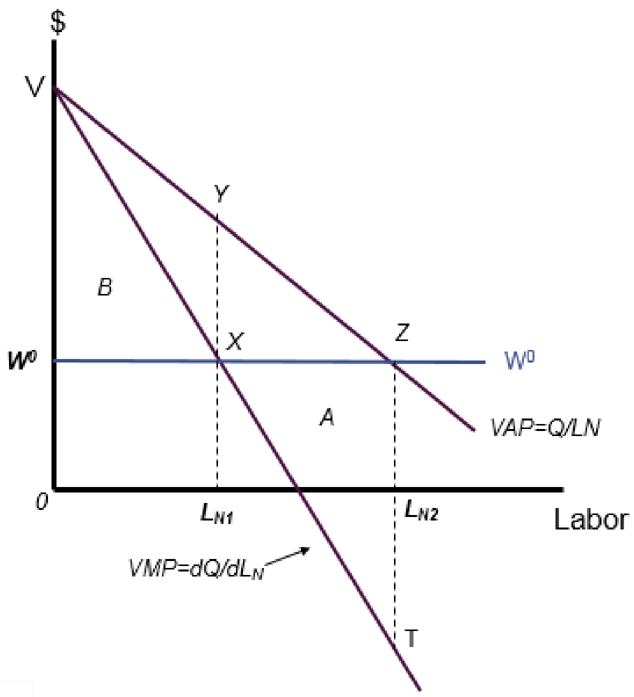

Figure 2. Property right regimes.

Source: Eggertsson, 1990, p. 86.

In the example, think of this figure as describing the extraction of natural resources, and that the only factor used in production is labour. The cost of applying labour to the natural resource is determined by the wage, W^0.[27] Labour is assumed to be homogeneous, so all labour units are of the same quality, thus unit L_i will produce Q/L_n, where Q is the total value of the output and L_n is the total number of labour units, i.e. the marginal unit generates average product. The extra unit of labour thus reduces the average product of existing labour units. This is shown by the slope of the VAP curve (value of average product). VMP curve (value of marginal product) summarizes these effects, i.e. it gives the net addition of total output when the marginal unit is added to production. If the natural resource is privately owned the owner takes into effect the additional labour units and employs L_{n1} units of labour. In other words, where the marginal product equals marginal cost. In this situation the wealth of the resource is maximized and is equal to triangle B (Eggertsson, 1990).

The outcome, when the resource is in open access, i.e. when the common property regime is in place, will not yield the same result. Under these circumstances, additional labour will not take into account the cost it imposes on other users, but only its own output, Q/L_n. Figure 2

[27] This is in accordance with the normal production function that dictates that wages are supposed to equal marginal costs.

gives an example of the external effects additional labour has on output. The effects of an infinitesimal increase in labour input at L_{n1} will reduce the productivity of the intramarginal unit by the distances XY. Hence, the net increase in output will be $L_{n1}Y - XY = L_{n1}X$, but the output of the marginal unit is $L_{n1}Y$. When each labour unit ignores the costs it imposes on others, new labour units will enter until $VAP = W^0$, i.e. when value of average production is equal to the opportunity cost of labour.[28] This will result in labour equalling L_{n2}. The resource rent will equal zero because of competitive forces, i.e. the net income from the resource is zero.[29] Thus, it is clear from this example that the net addition to output by extra labour units $(L_{n2} - L_{n1})$ is less than its contribution to alternative activates that is measured by W^0 (Eggertsson, 1990). To make this more prominent, consider ocean fisheries which can either be in private property or in common property.[30] Figure 3 gives an example of this situation, as argued by Gordon (1954).

[28] This can be thought of as being equivalent to what they can yield elsewhere.

[29] This can be seen by triangle A which is equal to the maximum rent the resource can yield, i.e. triangle B.

[30] Ocean fisheries are in private property regimes like ITQs all over the world. The best examples are New Zealand and Iceland. A total allowable catch is issued each year and owners of ITQs have harvesting rights in this total catch.

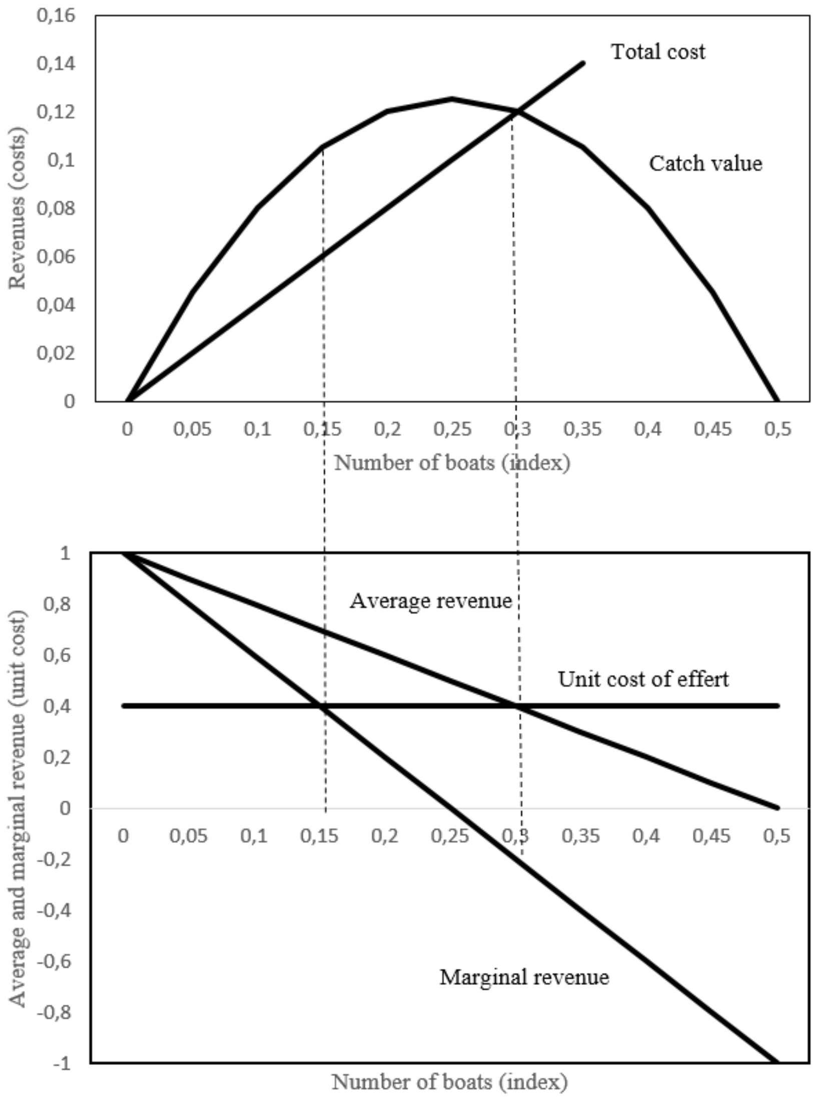

Figure 3. Ocean fisheries.

Source: Hannesson, 2004, p. 49.

The upper panel of figure 3 shows the sustainable revenue curve (catch value) and the cost curve. Both curves depend on the number of boats applied, i.e. the cost of fishing increases as more boats enter the fishery, and less and less fish are available for other enterprises. With more boats fishing, the catch value decreases after a certain point. This is because of the relationship between the natural growth function and the sustainable revenue curve, and the law of diminishing returns, i.e. catch increases with the number of boats up to a certain point, but then starts to fall.[31] The lower panel displays the sustainable revenue per boat (average revenue) and

[31] This is because the surplus growth of fish stock increases when the stock is reduced, but beyond a certain point the stock declines, and therefore revenue.

the sustainable revenue of an additional boat (marginal revenue) and how they depend on the number of boats (Hannesson, 2004).

The equilibrium under open access (common property) is where the average value per boat equals the cost per boat.[32] At that point the cost per boat represents the value of the resource that can be produced by the boat that could have been used in another activity. This is represented in figure 3 as 0.3 boats, or where costs and catch value intersect. Under private property regimes, the value of the fisheries is maximized when the additional value produced is equal to the cost per boat (where MR equals unit cost effort in the lower panel of figure 3), this is 0.15 boats on the figure. It is also represented where the difference between catch value and costs is maximized in the upper panel of figure 3 (Hannesson).[33]

The fact that the contribution of additional boats to total catch is negative under common property regimes highlights that not all is right in open fisheries. The effort spent on the fisheries represents commitments of factors in production, such as capital, labour etc. in the purpose of enhancing the standards of living. All of these factors can be used in other activities. Societies that allocate their production factors optimally will allocate them in such a way that the last unit allocated to all activities will yield the same value.

In figure 3, the optimal number of boats is less than under common property, this is because the fisheries take place on the margin, i.e. where marginal revenue equals unit cost of effort (sometimes represented as marginal cost). Under common property regime the value of catch per boat will be equal to the cost per boat, as was mentioned above. The factors that are employed unnecessarily in the fisheries under open access, will represent a loss of welfare. They could have been used in other sectors to produce greater value then they do in the fisheries (Hannesson, 2004).

The above result is also often known as “The Tragedy of the Commons” made famous by Hardin (1968). The problem arises because independent individuals, or firms with independent goals, have the ability and the incentive to extract from the resource, and will do so on a large basis (Eggertsson, 2003).

To sum up, when resources or commodities are in common property regimes, rational actors have little or no incentive to invest or improve the commodity and thus will withdraw from the

[32] Cost per boat represents the value of factors used on the boat: capital, manpower, fuel, etc.

[33] Economists often say that rational individuals make decisions on the margin, the above example illustrates this definition (this is what the author was taught in his first microeconomic class in university).

commodity in its natural form.[34] Short term horizons will most likely dominate, and long term investments will be neglected. This is because investors are uncertain whether they will capture the returns from their investments. Exchange and reallocations of commodities can't take place without exclusive rights, and thus, if they exist, commodities will not be used for higher valued uses.

No attention is paid to the optimal time preference or demand of the resource. This happens because actors have incentives to enter a race, to be first to the abundant commodity before it will be depleted and exploited too rapidly, relative to interest rates, thus withdrawal will be excessive and/or inefficient.[35] Individuals will use the resource as long as private marginal costs are equal to, or less than, the average returns from using the resource. In these circumstances, values and income stream from commodities, fall from their initial value. This happens mainly because individuals will not take into account the costs they are imposing on other individuals by their activities; excessive use will be encouraged and private and social returns will diverge. Thus, total production by all parties will exceed the social wealth maximization point (Eggertsson, 2003 and Libecap, 1986).

[34] In these situations rational actors will not take decisions on the margin.

[35] An example of inefficient withdrawal: individuals picking berries before they are ripe.

4. Impact of property rights on economic output and growth

Previously this paper has examined how economic incentives that are generated under regimes of property rights, in particular private property rights, contribute to non-wasteful use of commodities and hence to increased production (Furubotn, 2005). Property rights have many different attributes and their quality differs from one property to another and between countries. Through these different attributes and their qualities the performance of countries and welfare differ. In this chapter, growth theory and property rights will be studied together, and it will be shown how the latter has impact on output and growth.

It should be noted that economic objective is in fact not economic growth or consumption in itself, but the welfare that accompanies such goals. As such, the economic objective is to maximize the availability of desirables. Desirables are what individuals regard as valuable. Therefore, desirables can be considered anything that individuals are willing to put a positive price on. In a perfect market system where everything is tradable, desirables can be thought of as being the same as commodities. Thus, in this system they are equivalent to maximizing gross domestic product, GDP. In the real world there are no such things as perfect markets, therefore GDP cannot be regarded as the equivalent to the availability of desirables. GDP can nevertheless be regarded as a reasonable approach to the availability of desirables. The economic objective is thus to organize the social institutions that facilitate the economy so that economic activity maximizes net productions of goods (Arnason, 1999).[36]

Thanks to the contributions of Debreau (1959) in economic welfare theory, this assumption can be justified. The fundamental theorem of welfare economics can be stated in two sentences. The first sentence states that market equilibrium is always Pareto-efficient. In other words, in market equilibrium it is not possible to improve the well-being of any individual without compromising the well-being of another. This means that competitive markets in equilibrium will tend towards efficient allocation of resources. The second sentence states that that each Pareto-efficient solution can be a market equilibrium position. In other words, any desired wealth allocation can co-exist with maximum production and, indeed, the market system (Arnason, 1999 and 2004).

It was established in chapter 2 that the keys to sustainable long term economic growth are accumulation of capital and a higher degree of specialization. Likewise, from the discussion in chapters 3 it can be reasoned that for accumulation of capital, well defined property rights are

[36] Well defined property rights are one way to achieving this objective.

required. No individual or firm is going to save valuables in form of physical, human, or natural capital, unless they will enjoy the fruits of their investments. Accumulation of capital means sacrifice of current consumption. To buy and invest in physical capital requires savings, and savings can´t take place without sacrificing current consumption. To invest in human capital means to put time and energy into education and thus sacrifice current consumption. Also, if individuals do not have well defined property rights and accumulate capital, the accumulation might be seized by other individuals. In order to avoid a similar fate, capital should be consumed quickly. Weak property rights will thus lead to less, or no, accumulation of capital, and capital that does exist, will be quickly consumed and thus not used in the most efficient way (Arnason, 1999). Higher degree of specialization enables producers to focus on what they are best at, and to get better in what they do. This increases productivity and hence production without extra accumulation of capital. Specialization cannot occur without trade. For trade to occur, property rights are required. Trade is nothing but exchange of property rights. If individuals are to specialize in a single production, and improve, they will not be able to obtain various goods they desire and require.[37] If firms and individuals are to specialize and sell specialized products it will be based on the possibility of trade. Hence in societies where property rights are weak and trade cannot take place, there will be little economic specialization and resources will be poorly used. Specialization is also linked together with accumulation of human capital, thus societies that have acquired little human capital will experience lower degree of specialization (Arnason, 1999).

As has been stated through much of the essay, property rights are seldom perfect. Even well-defined property rights will often be of low quality, and thus not generate the economic efficiency they are supposed to. This is because property rights are collections of many different attributes that affect the quality of the title. Professor Scott (1996, 2000) has emphasized that the most crucial attributes of property rights are: *Security*, *exclusivity*, *permanence* and *transferability*. Arnason (2007) has explained the content of these attributes:

[37] In these situations individuals will depend on other individuals to provide them with essential goods. Example: There is an individual who works as a farmer and another who works as a banker. The farmer provides the banker with food and the banker provides the farmer with capital, so production can take place. Thus each depends on the each other to make ends meet.

Security: Sometimes described as, *quality of title*, refers to the ability of the owner to withstand challenges by individuals, institutes, the government etc. to preserve his property right title. This measure is best thought of as the probability that the owner of the title will hold on to his property right with complete certainty or lose his title.

Exclusivity: This attribute refers to the ability of the owner to exclude other individuals from his commodity. Thus he will utilise and manage his property in a manner he deems most fit to maximize the expected flow of income or wealth without interference from others that might reduce the value of the commodity. Enforceability is an important aspect of exclusivity. For example, the ability of title owners to enforce the exclusive right he or she has over the property.

Permanence: Refers to the duration or the time span the property right holder can expect to hold his title. This attribute is closely related to security, i.e. if the title is terminated, then permanence will be reduced to zero. An example can be rental agreements, for they provide total security of title, but only for a limited time span.

Transferability: Refers to the ability to transfer title of property rights, or some aspects of them to other individuals. This attribute is economically important because it represents the ability of resources to be allocated between competing users, and therefore to their optimal allocation.

It is useful to visualise these attributes of property rights on a four dimensional space diagram know as a characteristic footprint of property rights (Arnason, 2007). This is illustrated in figure 4.

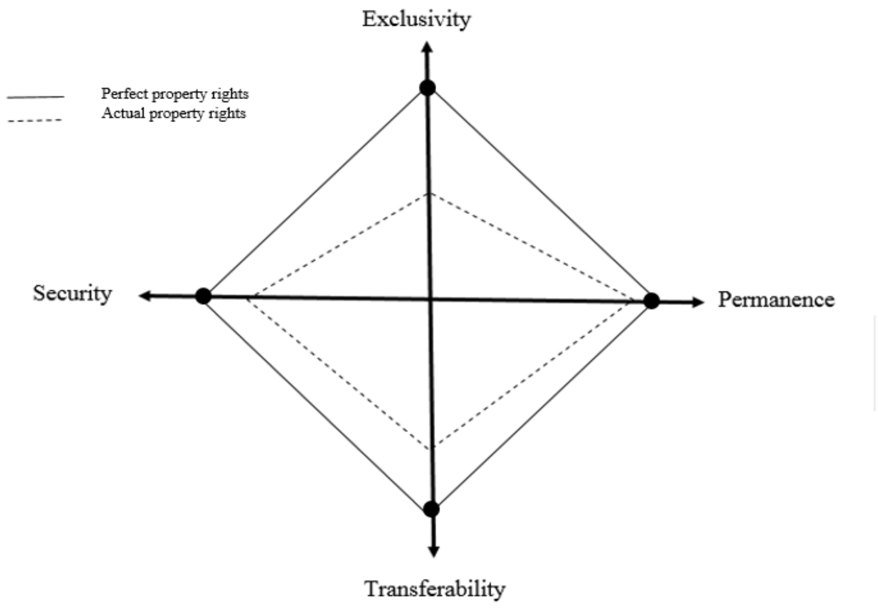

Figure 4. Characteristic footprint of property rights.

The map of property right characteristics measures the quality of the property rights attributes on a scale of zero to one. One signifies that the property right holds all of these attributes. Zero means that the property right does not hold any of these attributes. The outer line on the characteristic footprint represents a perfect property right and the dotted line represents a fictional property right that does not hold all of the attributes in highest quality (Arnason, 2007). The quality of property right will differ depending on how the attributes of the right differs. This will affect the incentives of individuals and firms, and how the resources will be employed. Hence, it will affect production activities and therefore welfare.

A simple fisheries model can be used to examine the relationship between the attributes of property rights and economic efficiency. Consider the profit function $\Pi(q,x)$, where q represents the level of production and x represents the existing stock of natural resources, and both variables can vary over time.[38] The profit function, although not stated, will also depend on other parameters such as prices. The function is assumed to be non-decreasing in x, and concave in both variables. It is assumed that the profit function has a maximum at some level of production.[39] Natural resources will vary over time according to the differential equation: $\dot{x} = G(x) - q$. The function $G(x)$ describes the natural growth of the resource, and it is assumed to be concave. If the natural resource is non-renewable, the natural growth function will simply be zero. In cases of renewable resources, such as fish stocks, there will exists resource levels that fulfil the conditions, $x > 0$ and $G(x) > 0$ for $\bar{x} > x \geq 0$ so that $G(x) > 0$ (Arnason, 2007).

The first welfare theorem states that if all prices are true, then profit maximisation is necessary for Pareto-efficiency to occur.[40] Thus, solving the following maximization problem will give the socially efficient utilisation that maximizes social welfare (Arnason, 2007):

$$\underset{\{q\}}{\text{Max}}\, V = \int_0^\infty \Pi(q,x) e^{-r \cdot t} dt, \tag{4.1}$$

$$subject\ to: \dot{x} = G(x) - q,$$

$$q, x \geq 0,$$

$$x(0) = x_0$$

[38] The function $\Pi(q,x)$ represents the highest profit function, i.e. the one that yields the most productive technology.

[39] Non-decreasing means that the resource is not detrimental to profits.

[40] If all prices are true then they will reflect marginal social benefits. This is most likely to happen when there are well-defined property rights over commodities.

The functional V in equation (4.1) measures the present value of the profit function on the production path q, and r represents the rate of discount. Using optimal control theory to solve this problem will lead to the following necessary conditions, see appendix A for formal derivation (Arnason, 2007):

$$\Pi_q = \mu, \ \ \forall t \ provided \ q > 0, \tag{4.2}$$

$$\dot{\mu} - r \cdot \mu = -\Pi_x - \mu \cdot G_x, \ \ \forall t, \tag{4.3}$$

$$\dot{x} = G(x) - q, \ \ \forall t, \tag{4.4}$$

$$\lim_{t \to \infty} e^{-r \cdot t} \mu(x^{\circ} - x^{*}) \geq 0, \tag{4.5}$$

In the last condition (transversality condition), x^* represents the resource along the optimal path, and x° of any other attainable path. The variable μ represents the shadow value of the resource at any given time and equation (4.3) delineates its evolution over time.

The profit maximizing equilibrium is defined by the following equations:[41]

$$G_x + \frac{\Pi_x}{\Pi_q} = r \tag{4.6}$$

$$G(x) = q \tag{4.7}$$

Solving equations (4.6) and (4.7) leads to profit maximizing level of resource and production. These paths depend on the initial level of resources, and the parameters that the profit function and the natural growth function depend on. Hence, when these profit maximizing paths are chosen, they will maximize the present value of equation (4.1) and thus the wealth and welfare of society (Arnason, 2007).

The shadow value of the resource needs to be explained a little further. The shadow value μ, measures resource rents per unit of production at each point in time true. Therefore, representing pure profits of the production activity and its contributions to *GDP*.[42] Also, μ can be regarded as the equilibrium price between supply and demand of harvest. An owner of the resource would allow q to be extracted from the resource for the price μ, and an individual would be prepared to pay μ to extract from the resource. The supply curve in equilibrium is defined from equation (4.6) as: $\mu^s = \Pi_x/(r - G_x)$, and the demand curve is defined as: $\mu^d = \Pi_q$ (Arnason, 2007).

When property rights are perfect, i.e. when there is full *security*, *exclusivity*, *permanence* and *transferability* (see figure 3), the owner will do his best to solve the social problem that was

[41] See appendix A for calculations.

[42] This only holds in perfect competition.

expressed in equation (4.1). The only limitations to the maximisation he faces are limits of technology and the law of nature. He will even have incentives to do his best in solving these limitations. If other firms or individuals can solve the maximisation problem better, then the owner of the title will sell his title to the more efficient firm, because that is how he is able to maximize his private net returns (Arnason, 2007).

What effect will it have on individual maximization if security of title alters? As was stated above, security refers to the certainty in which the rights will be held. Title holders can hold their rights intact or lose them completely, thus the level of security refers to the probability of losing or holding the title. Property rights can be removed in many different ways. Governments can abolish rights, and/or they can pass laws which may make it difficult for firms to make a profit. Also, if property rights are not honoured, for example, because of a poor legal system, security of the title will be lower than its initial level.

The probability that an owner will lose his title during a certain period of time while he holds the title can be represented with ρ, sometimes called "the insecurity parameter", and $(1-\rho)$, which represents the probability the owner will retain his title. The probability that an owner will retain his property is represented in continuous time by, $e^{-\rho t}$. Hence, less than full security $\rho > 0$ has the same effect as the rate of discount, rewriting the firm's profit function accordingly (Arnason, 2007):

$$\underset{\{q\}}{\text{Max}}\, V = \int_0^{\infty} \Pi(q,x)e^{-i\cdot t}dt, \qquad (4.8)$$

$$subject\ to\colon\ \dot{x} = G(x) - q,$$

$$q, x, \geq 0,$$

$$x(0) = x_0$$

Where i is the new discount rate, i.e. $i = r + \rho$. Profit maximization production in continuous time depends on the rate of discount, i.e. it determines the present value of the resource. It is a simple mathematical problem to show that when a rate of discount increases, the value function (4.1) and (4.8) is reduced. Compared to perfect property rights, this leads to the first result, "less than fully secure property rights are economically damaging" (Arnason, 2007).

The relationship between efficiency and the insecurity parameter ρ is harder to work out. However, with simple logic it can be argued that with the greater value of the insecurity parameter ρ, efficiency declines. Result one established that $\rho > 0$ is economically damaging. Thus for any level of r and ρ there can exist a rate of discount, r° such that $r^{\circ} = r + \rho$. If this were the case, then the path that the firm chose to maximize profit would have been optimal.

But result one established that any increase in uncertainty will reduce profits. Thus leading to monotonicity and establishing the second result: “economic efficiency declines monotonically with the level of uncertainty” (Arnason, 2007). Finally, reduced security will also reduce the shadow value of the resource, thus leading to a higher harvest rate. To see this consider equation (4.3) with some slight adjustments (Arnason, 2007):

$$\mu = \frac{\Pi_x}{(r+\rho-G_x)} < \frac{\Pi_x}{(r-G_x)} \qquad (4.9)$$

The role of exclusivity for owners refers to their ability to exclude others from using the resource, thus being able to use the property without interference from others. Lack of exclusivity can take several forms in our basic fisheries model, including: seizure of output, taxation and non-exclusive access to resources. All of these examples will affect the incentives of owners and the use of the resources (Arnason, 2007).

Taxation and seizure of output are virtually identical. It is quite obvious that taxation will have a negative effect on the profit function of a firm. Rewriting the profit function reveals this: $\Pi(q,x) - \tau \cdot q$, where τ represents the rate of taxation. Taxation also affects the behaviour of the title holder from what is socially optimal. For instance the equilibrium condition from (4.6) will change too (Arnason, 2007):

$$G_x + \frac{\Pi_x}{\Pi_q - \tau} = r \qquad (4.10)$$

This result shows that when a higher level of benefits is expropriated, the marginal stock effect will increase, and thus the optimal biomass level. The impact this has on the property right holder is to divert him from the socially optimal production path, and harvest more slowly. Hence, it will be socially costly to impose taxation regimes, thus reducing the wealth of the programme and the welfare of the society (Arnason, 2007). This is similar to the results that Johnson (1995) argued, except that he looked at a case where property rights values were taxed. This can be thought akin to when quota values are taxed. He found out that the incentives of fishermen would change but in reverse of what was earlier formalised, i.e. their incentives change in the direction that will be more profitable for them to increase their harvesting rate. Both regimes change the production path from optimal, thus reducing social welfare.

Non-exclusive access to a resource will reduce the wealth of the resource from what was socially optimal. A firm’s production opportunities are reduced as more and more firms are able to use the resource, thus reducing overall profit and efficiency. A simple way to see this is to consider the shadow value of the resource. As more and more firms use the resource the value will drop. Thus, in equilibrium, the shadow price can be represented by (Arnason, 1990 and 2007).

$$\mu(i) = \mu^{*} \cdot \alpha(i), \tag{4.11}$$

In the above equation $\mu(i)$ represent firm's i´s shadow value of the resource, and μ^{*} represents the social optimal shadow value and $\alpha(i)$ is firm's i´s share in the resource. Thus, it is quite obvious that when more firms enter the race for a resource, the shadow value will drop and therefore the wealth of the resource, and it will be harvested on a higher level.[43] Hence, fishermen will have the same incentives as form the open access result shown in chapter 3.1. Ergo, less exclusivity gives the same result as less security, "less than full exclusivity is economically damaging" and "economic efficiency is monotonically increasing in exclusivity" (Arnason, 2007).

The role of permanence needs to be reviewed. Consider what impact a finite duration of property right has on production activities. If duration of the property is T, i.e. the owner knows for certain that the property right will expire at T, the owner will solve the limited time problem (Arnason, 2007):

$$\underset{\{q\}}{\text{Max}}\, V = \int_0^T \Pi(q,x) \cdot e^{-rt} dt, \tag{4.12}$$

This problem is subject to the same constraints as before. The necessary conditions for solving this problem are the same as before except for the transverality condition (4.5) it will be replaced by:

$$\mu(T) \geq 0, x(T) \geq 0,\ x(T) \cdot \mu(T) = 0 \tag{4.13}$$

Condition (4.13) shows that if the resource will not be completely drained during period T, the shadow value of the resource will equal zero. This solution does not come as much of a surprise. Since the firm title will expire at T, it will not value the resource from that time on. Condition (4.2) states that along the optimal path in continuous time, $\Pi_q = \mu$, holds. So at the expiration time $\Pi_q = \mu(T) = 0$ will apply, thus resource rents will be zero at terminal time, similar to the common property case. Limited duration on property rights will lead firms to consider only short-term profit options and so move from the socially optimal production path to maximize the present value of the property during its duration. Therefore, giving the same results as before, limited duration is economically damaging, and will reduce efficiency (Arnason, 2007).

[43] See appendix A for calculations of this statement.

Although the role of tradability will not be examined formally in this essay it will be mentioned briefly. To attain economic efficiency only the best firms should produce goods at each given time. When property rights are transferable, economic efficiency will occur through market transactions, because private profit maximisation will usually ensure this. It is then quite straight forward to see that any restrictions on transferability will reduce efficiency and thus social welfare.

4.1 The general case

Through examining the impact they have on the efficiency of fisheries, it has been shown that any restrictions on the quality of property rights will reduce social wealth and efficiency. Hence, we can conclude that property rights and their quality influences the wealth and welfare of nations. This can be formalised in a more general way with a little altering of the growth theory equations from chapter 2.

Consider the economy wide production function:

$$y = Y\big(k, l, a(\emptyset)\big), \tag{4.14}$$

The variables y, k and l are production, capital and labour use. The variable $a(\cdot)$ can be thought of as meaning the efficiency of the economy and is a function of property right quality, $\emptyset$. Otherwise, the production function has the same attributes as the neo-classical growth theory models of chapter 2. The efficiency variable plays a key role in analysing the attributes of the model and what impact property rights will have on economic growth and output (Arnason, 2001).

Capital is assumed to accumulate according to the following differential equation:

$$\dot{k} = i - \delta k, \tag{4.15}$$

Where i represents investment and δ the depreciation rate of capital. It is assumed that investment is a constant, s, of production, i.e. $i = sy$. Actually it can be assumed that investment is a function of property right quality but that will make the calculations rather messy and so not done here. However, it would still yield the same result. In equilibrium, ($\dot{k} = 0$) it is required that $y = (\delta/s) \cdot k$, holds. Hence, for stability in equilibrium to hold, it is required $\delta\dot{k}/\delta k = sY_k - \delta < 0$, holds.

To see what effect, change on the quality of property rights has on the economy, the total derivative of equation (4.14) is taken:

$$dy = Y_k(s/\delta)dy + Y_l dl + Y_a a_{\emptyset} d\emptyset, \tag{4.16}$$

For simplification it is assumed that labour is constant, i.e. *dl*=0. This seems quite reasonable at least for short-term effects. $d\emptyset$ is divided through equation (4.16) to see what effect a higher quality, of property right has on production:

$$dy/d\emptyset = Y_a a_\emptyset/(1-(s/\delta)\,Y_k), \quad (4.17)$$

The initial effect of property rights on production is $Y_a a_\emptyset$, and this effect is then increased even further by the multiplier $\sigma \equiv 1/(1-(s/\delta)Y_k)$. If the economy is in a stable equilibrium then it will apply that $\sigma > 1$. The process of higher quality property rights takes place as follows. A higher quality of property rights will yield more profits on the optimal production path and thus, with the extra profits investment, will be increased. Therefore increasing profits even more. This process will carry on until the economy reaches its new long term equilibrium, as explained in figure 5 (Arnason, 2001).

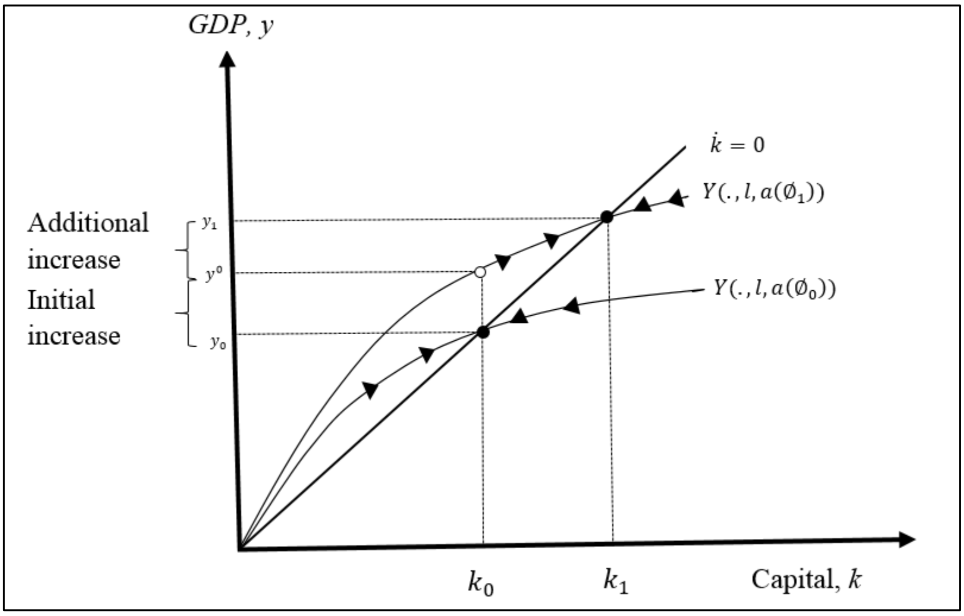

Figure 5. Economic growth effects of higher quality of property rights.

The initial equilibrium in figure 5 is (k_0, y_0). The initial effects of higher property rights will be to nudge the production process to a higher production path, $Y(.,l,a(\emptyset_1))$ and the short-term equilibrium will be (k_0, y^0). However at this point, excess demand will be for capital and thus an investment period will take place until the long term equilibrium is reached (k_1, y_1) (Arnason, 2001).

This solution shows that an increase in property right quality will increase economic production, GDP. The same methodology can be used to show what effect an increase in property right quality will have on the real wage of an economy. Thus, giving a better illustration of the correlation between how property right raises welfare. In a well-functioning economy, real wage should equal the marginal product of labour, thus:

$$w = Y_1\big(k, l, a(\emptyset)\big), \tag{4.18}$$

where w represents real wage. By taking the total derivative of equation (4.18), with respect to $\emptyset$, and dividing it with $d\emptyset$, yields:

$$dw/d\emptyset = Y_{lk}\, dk/d\emptyset + Y_{ll}\, dl/d\emptyset + Y_{l\emptyset}\,, \tag{4.19}$$

The last term in equation (4.19) represents the initial effects of property right increase on real wage, i.e. if wage was initially determined with equation (4.18). Reader interest does not lie on the initial effect property rights have on wage, and thus the last term of equation (4.19) will equal to zero for the time being. As usual, it is assumed that supply of labour is constant, thus the term $dl/d\emptyset$ in equation (4.19) will equal zero. Hence, on the investment process, i.e. from level k_0 to k_1 the effects of property rights will be (Arnason, 2001):

$$dw/d\emptyset|_2 = Y_{lk}\, dk/d\emptyset \tag{4.20}$$

where the representation $dw/d\emptyset|_2$ reminds the reader that the real wage process on the investment process period is being examined. Earlier it was defined that in equilibrium $y = (\delta/s) \cdot k$ holds. From this definition it can be seen that $dk/d\emptyset = (s/\delta)\, dy/d\emptyset$ holds. This information, and equation (4.17), will yield the next equation (Arnason, 2001):

$$dk/d\emptyset = (s/\delta) \cdot [Y_a a_\emptyset/(1 - (s/\delta)Y_k] = (s/\delta) \cdot \sigma \cdot Y_a a_\emptyset \tag{4.21}$$

Hence, we can write the total change in real wages on the investment period as:

$$dw/d\emptyset|_2 = Y_{lk} \cdot (s/\delta) \cdot \sigma \cdot Y_a a_\emptyset \tag{4.22}$$

Equation (4.22) reveals that as long as the derivative Y_{lk} is positive, real wage change in the investment period will be positive.[44] Earlier it was defined that $Y_a a_\emptyset > 0$ and $\sigma > 0$ hold. Thus, it must be that $dw/d\emptyset|_2 > 0$, i.e. the change in real wage will be positive. The total effect an increase in property right quality will have on real wage can be summed up by the following equation (Arnason, 2001):

$$dw/d\emptyset = Y_{l\emptyset} + dw/d\emptyset|_2, \tag{4.23}$$

[44] Our production function is assumed to be concave and as such it is not hard to assume that $Y_{lk} > 0$ holds.

An increase in quality of property rights will increase real wage and thus, contribute to the overall social welfare can be assumed (Arnason, 2001).[45]

In this chapter it has been proven in theory, and shown, how property rights, and a higher quality of them, have a positive effect on economic growth and output. This is the same result that North (1976) argued. Acemogle and Robinson (2008, 2010 and 2012) have also asserted the main reason for the income gap that has formed over the last two centuries is due to certain societies having poor social infrastructure where property rights do not hold. This explains why some nations have experienced poor growth and lack of social welfare. For example, Acemogle and Robinson have pointed out that one of the main reasons why sub Saharan Africa is so poor is that property rights are very insecure and very badly organized. As such, the markets do not function in a way that will lead to efficient allocations of resources, thus prosperity and welfare are reduced.

[45] Even though $Y_{l\emptyset}$ would be negative, which is highly unlikely because the initial effect of property right was to increase profits, and thus wages should rise. But in that unlikely situation, the total effect could still be to raise real wage as $Y_{l\emptyset} < dw/d\emptyset|_2$ would probably hold.

5. The case of the Icelandic quota system

Iceland is a 103.100 km^2 island located in the North Atlantic Ocean and sits astride the huge mid-Atlantic ridge-rift system. Iceland lies between latitudes 63° and 67° N. and longitudes 25° and 13° W. It lays just south of the Arctic Circle. In 2014 the Icelandic population was recorded as being 325 thousand, in nominal terms its GDP was approximately $14.2 billion, and its GDP per capita was approximately $52 thousand. In 2013 its GDP per capita was the 18th highest in the world according to the World Bank.

Like most of the OECD countries, the Icelandic economy is fundamentally structured as a market economy. However, it differs in some primary respects from the other OECD countries in terms of its small size, which yields relativity low economic competition, much government involvement, and its dependence on marine exports. Throughout the 20th century fish products contributed towards 70-90% of its exports, and since the beginning of the 21th century they have contributed 40-60% of its exports (Statistics Iceland, 2015).[46] Iceland´s production sector consists mostly of resource extraction, agriculture and manufacturing industry. Table 1 below refers to most of these sectors.

Table 1. GDP by production sectors.

5 year average	*73-77*	*78-83*	*84-88*	*89-93*	*94-98*	*99-03*	*04-08*	*09-13*
Agriculture	5,2%	5,0%	3,9%	2,8%*	1,4%*	1,2%	1,0%	1,2%
Fishing	7,5%	7,6%	8,6%	9,3%	8,3%	7,1%	4,9%	6,0%
Fish processing	6,8%	7,5%	6,3%	4,9%	4,3%	3,2%	2,4%	3,7%
Construction	11,8%	9,5%	8,5%	8,3%*	8,7%*	8,4%	10,1%	4,4%
Transp., storage and comm.	9,8%	8,6%	8,1%	7,5%*	6,1%*	5,6%	4,4%	5,3%
Finance, insur. and real estate	16,8%	18,6%	18,6%	19,5%*	9,9%*	13,0%	19,0%	20,2%
Goverment services	12,8%	14,7%	14,9%	16,1%*	18,3%*	21,1%	19,5%	18,9%
Other	29,3%	28,5%	31,1%	31,6%*	43,0%*	40,4%	38,7%	40,3%

Source: *Statistics Iceland and Icelandic historical statistics (Hagskinna).*

** Data is missing for all production sectors except fishing and fish processing for the years 1991-1996.*

To this day, (2015), in terms of its contribution to GDP and exports, the marine industry remains the biggest single industry in Iceland. In 2013 its direct contribution to GDP was approximately 10% (Statistics Iceland, 2015).

Economists and historians alike have emphasized the most important industry in Iceland

[46] Aluminium products have become ever more important since the late 20th and early 21th century, and in 2014 contributed to 37% of Iceland´s export value. Marine products where 40%.

during the 20th century was the marine industry, and have stated that Iceland´s rapid economic growth was due to the expanding fishing industry (Nordal and Kristinsson, 1987; Snævarr, 1993; Arnason, 1994). These claims are supported by statistics. The bulk of Iceland´s exports during that period came from marine products (as mentioned earlier on page 42), and by the simple fact that every time the fishing industry went through a recession, due to poor catches or poor external conditions like lower prices on marine products, Iceland´s economy experienced a similar fate.

When looking at national accounts like table 1, the numbers do not quite add up. How is it possible that an industry that has averaged about 25% of GDP from turn of the 20th century to World War II, and has accounted for, on average, about 15% of GDP since that war, can have these effects on economic growth? Agnason and Arnason (2005 and 2007) have argued that the fishing industry is a so called economic base industry for Iceland, and that in conventional national accounts it´s contributions to GDP are underestimated.

The concept of the economic base can be adequately thought of in illustrative form. Imagine that oil or minerals are found in the middle of frozen tundra. Extracting these resources will require labour, and that labour will demand a range of local services. This will mean that a community will be build up to serve the extraction industry as well as other activities. Not only will these local economic activities result in forward and backward linkages to the extraction industry, they will also result in there being linkages to other industries. Together it is quite possible that these "combined" industries will add more to the local GDP then the initial extraction industry. Now within the above scenario, imagine that a local cinema or hairdresser becomes insolvent and closes down, the result form this will be that the population will save its income, or spend it, on other activities. Only if these alternative expenditures are less than were being spent before will the local GDP be reduced, i.e. will be reduced by some fraction of the net income of activities that have closed down. In the case of the extraction industry closing down, due either to insolvency or resources having been depleted, the local economy will not only be reduced, it will probably fold. This is a consequence of the whole community having been built around the extraction sector. The collapse of backward and forward linkages between the extraction industry and other local services will cause a chain reaction that will eventually undermine the foundations of the community. The point being that the extraction industry was the reason why people settled, built homes and raised families there, and why an economy existed in the area in the first place. Without the extraction industry, the surrounding town will wither and die. (Agnarson and Arnason, 2007).

Agnarson and Arnason (2005 and 2007) have argued that the fishing industry in Iceland is an economic base industry like the previous example. The research is briefly explained in the following lines. The economic base multiplier can be defined by the following equation:

$$E(y,\emptyset) \equiv \frac{dy}{d\emptyset} \cdot \frac{\emptyset}{y} \qquad (5.1)$$

Equation (5.1) shows the relationship between the elasticity of GDP, y, with respect to the extraction industry, $\emptyset$, defined as $E(y,\emptyset)$, the economic base multiplier is, $dy/d\emptyset$ and $\emptyset/y$ is the share the extraction industry has in GDP.[47] The research of Agnarson and Arnason was based on finding this multiplier for the fishing industry and noting whether a long term relationship existed between the industry and GDP, and whether other industries would yield a similar multiplier.

To do this they employed an error-correction model (ECM) on Icelandic data that would be able to capture both short- and long-run impact of the fishing industry on economic growth. This particular methodology is employed in three steps. In the first step, variables that are used are tested for their order of integration.[48] In the second step, the long-run relationship is estimated, and the residuals from the estimation checked for stationarity. In the final step, the ECM is estimated and the number of co-integrated relationships are checked.[49] In Agnarson and Arnason's research findings, the Johansen trace test suggested that there was one co-integration relationship, which meant that there existed one long term relationship between the variables. The estimation of the ECM revealed the output elasticity of the fisheries was 0.31%, meaning that an increase in marine production by 1% would lead, in the long run, to an increase in GDP by 0.31%. Thus from equation (5.1), if the share of marine production is 10% as it was in 2013, it can be established that the economic base multiplier from the fisheries, $dy/d\emptyset$, will amount to 3,1. The research then examined other significant industries in Iceland and whether there existed a long-term relationship between them and GDP, and if they yielded the same multiplier. Construction and transport sectors were examined because they have had a similar fraction of GDP over the years as the marine industry. The conclusion from the estimates was there did not exist any long-term relationship between these industries and GDP, as was the case for the marine industry. The results strongly support the theory that the fishing industry is

[47] In the case of Iceland the extraction industry can be thought as on a par with the marine industry.

[48] These variables are logarithms of transformations of GDP, marine production, capital stock and labour.

[49] The Johansen test is employed to check for the number of co-integrated relationships.

an economic base industry for Iceland, and habitual and characteristic national accounts clearly underestimate the importance of the industry for the Icelandic economy (Agnarson and Arnason, 2007).

Recent research done on the forward and backward linkages of the marine industry in the Icelandic economy has shown that from the year 2000 and onward, 20% of GDP has on average been from the marine industry and linked industries. In 2012 it was 23%, but was highest in 2001, when it contributed to 28% of GDP (Heimisson, 2014). Professor Arnason (1995 and 2011) arrived at a similar conclusion, and in 1995 he estimated that approximately 26% of GDP could be traced to forward and backward linkages of the fishing industry.

According to the base multiplier, it can be estimated that on average, from 1973 to 2000, marine industry and linked industry have been responsible for roughly 30% of GDP. The most important industries that are linked to the marine sector are: maintenance of vessels, plants and equipment, manufacturing of fishing gear, fish-processing machinery, equipment and packaging. Some companies in these industries have grown to be the biggest companies in the country, for example, Marel which started out back in the 1980's by providing the marine industry with industrial scales. Today Marel is the biggest company in Iceland and provides equipment to poultry, fish, meat and other processing industries all over the world, and generates over 90% of its revenue on foreign soil. In 2014 its revenue was 712 million EUR (Marel, 2014). This is but one example of backward linkages, later in the essay further examples of backward- and forward linkages will be provided, and explanation will be given of how they have helped both the marine industry and the Icelandic economy evolve.

5.1 Evolution of the fishing industry

This sub-chapter discusses the evolution of the marine sector and the Icelandic economy from the end of World War II. There was much investment in trawlers and marine processing plants during the latter years of the Second World War which yielded significant economic growth during 1944-1947. The Icelandic economy went through a recession from 1949-1955, mainly because of poor catches in herring, plus the price of marine products in international markets fell. From 1962-1966 Iceland averaged 9% economic growth. Much of that growth can be traced back to substantial herring catches during those years. However, due to overfishing, the herring stock collapsed in the following years and with it the Icelandic economy. GDP was reduced by 1.5% in 1967 and 5.5% in 1968 (Statistics Iceland, 2015). In 1967 to counter the fall in the marine sector, the Icelandic currency was devaluated by 25%, and again in 1968 by 35%. In the 1970's, constant economic growth occurred. On average GDP grew by 8.5%, on a yearly basis. This growth was mostly thanks to the marine sector, and during the decade catches expanded by 10%, and their values 13% on average on a yearly basis (Statistics Iceland, 2015).

An investment period followed in the wake of this, and many new trawlers and fish processing plants were built. Another important development happened during these years when the fisheries jurisdiction was extended from 12 miles to 200 miles. It was greatly opposed by foreign fishing fleets, most bitterly by the British fishing fleet. Iceland engaged in a so called "Cod-War" with Great Britain during those years. On December 1. 1976 the last English trawler sailed out of the Icelandic fisheries jurisdiction (Agnarson and Arnason, 2005).

In chapter 4 (page 32) it was noted that exclusivity is one of four main characters of property rights. The extension of the fisheries jurisdiction can be seen as the first step in better utilisation and management of the fish stocks around Iceland leading to more profits in the industry, and in economic growth in Iceland. Other factors also played a role for the success Iceland celebrated during the decade.

The fish stocks could not sustain the exploitation that followed the extension of the jurisdiction, and circa 1980 they collapsed.[50] During the same period marine prices fell substantially. The Icelandic economy almost stood still during those years. To make operating conditions more favourable for the marine sector the Icelandic currency was devalued in both 1982 and 1983. During those years it became ever more clear to Icelandic authorities that some kind of measure had to be taken to protect the demersal fish stocks from being overfished (Arnason, 1995).

The long-term economic decline in the performance of the Icelandic marine sector had been observed by fishery authorities and certain measures had been implemented before the extension of the fisheries jurisdiction to 200 miles in 1975. When the herring stock collapsed in 1969 an overall quota was imposed on the fisheries, and in 1972 a complete moratorium on herring was introduced. In 1976 an "individual-vessel" quota system was introduced on herring fisheries. Following the extension of the fishing zone in 1976 the cod fisheries where subjected to an overall catch quota (which had little effect), and in 1977 an individual effort restriction was implemented in the form of limited fishing days. Further, in 1979 vessel quotas in the herring fisheries were made transferable. In 1980, following the collapse of the capelin fisheries, the capelin fisheries were introduced to the individual vessel quota system (Arnason,

[50] Among those who collapsed were the cod and capelin stocks.

1995). Figure 6 shows the evolution of fish catches caught by Icelandic fishing vessels from and between 1945-2013.

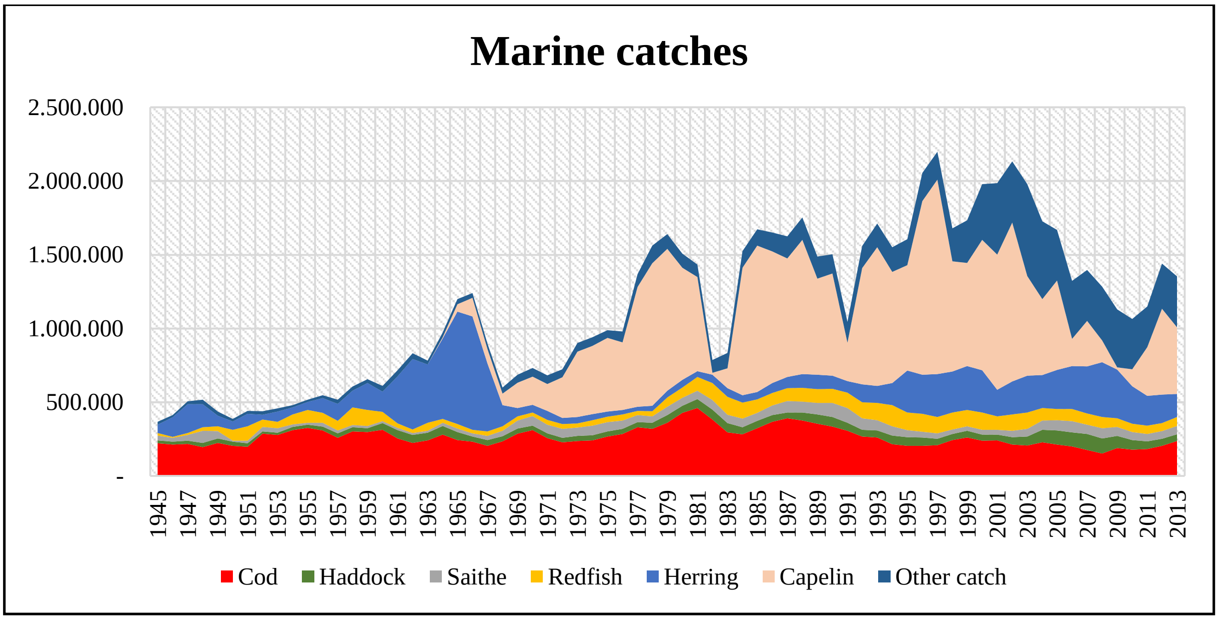

Figure 6. Marine catches from 1945-2013.

Source: Statistics Iceland.

Even though the foreign fleets were mostly driven away from the Icelandic fishing zone in 1972-1976, the logic and incentives of the Icelandic fishermen were slow to adjust to their newly acquired resources. Instead of managing the resource in an "economically sensible" way, they enlarged the fleet and expanded into the void left by the foreign fleet. Fishing effort increased by 31% during this period and investment also increased intensively (Hannesson, 2006). Although it had only averaged 25% in the 1970's, on average, investment increased by 46% during the 1980's. While catches and values only increased by around 10% and 13% during the period, profits were negative for four years during the decade, and on average, operating losses were 0.4% of revenue. The nature of this problem can be explained by Gordon's "common property problem" (1954).

The fisheries problem actually overturns conventional economic theory. Economic theory predicts free access and competition is the desired institutional framework for economic activity, which will yield the optimal solution and maximize social welfare. However, free access and competition in ocean fisheries lead to reduced output, and lower real income. The common property nature of ocean fisheries is best described in figure 7.

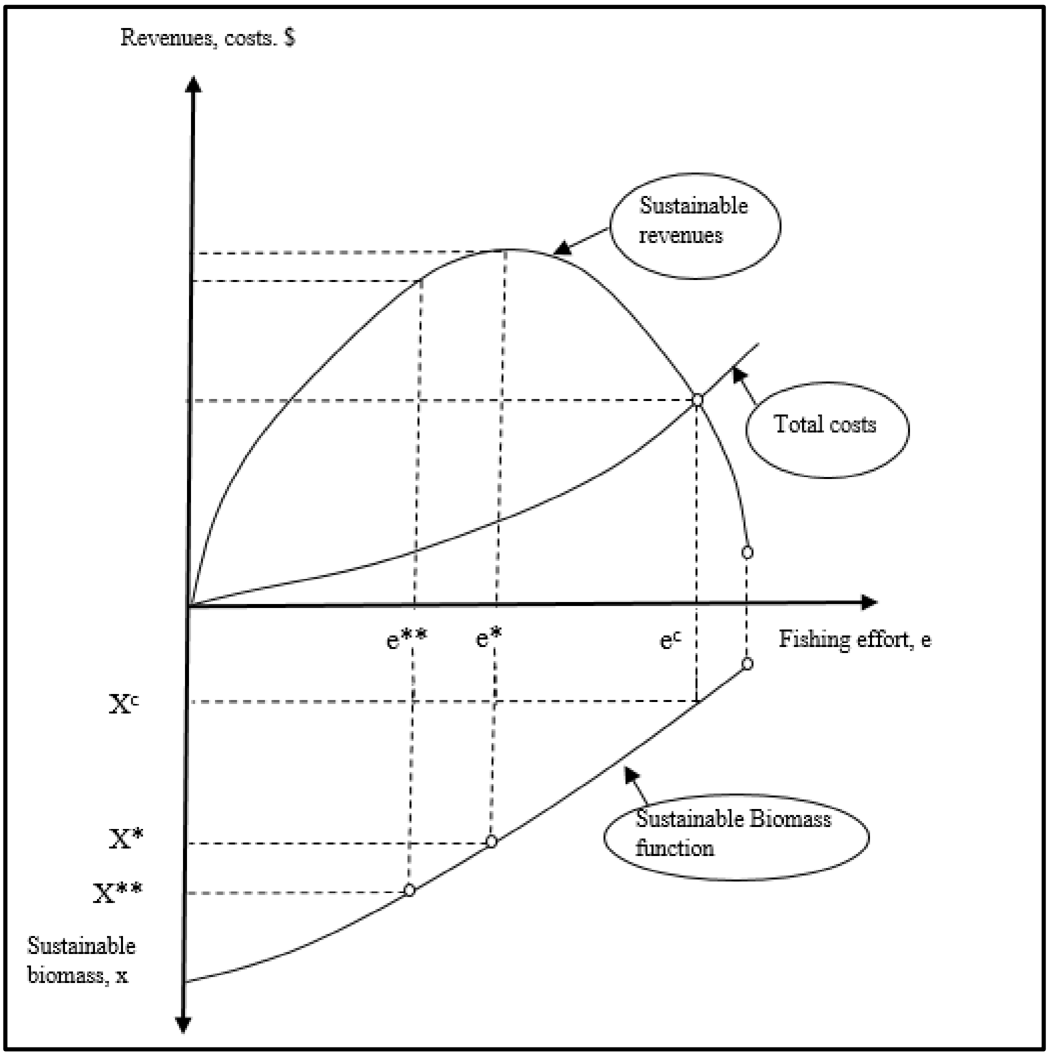

Figure 7. Basic sustainable fisheries model.

Source: Arnason, 2008.

Figure 7 is a basic fisheries model. The concave curve is the sustainable revenue curve and reflects the true social revenue from fisheries. The convex curve reflects the total social cost from conducting the fisheries. The curve on the lower part of the figure is the sustainable biomass function of the fish stock. The biomass is at its maximum size the further down the curve it goes, i.e. to the left. Fishing effort is measured on the horizontal axis. Hence, costs are growing in fishing effort, which is in accordance with the basic production functions, i.e. increasing marginal costs. Sustainable revenues grow in fishing effort but by a certain point, revenues begin to fall. This is according to the basic production functions.

The fisheries will only reach equilibrium in open access where costs and revenue meet, i.e. in point e^c and x^c. The course of the fisheries will usually run as follows: in the beginning the resource stock are high and therefore catches will be good: the fishermen will earn high returns from their investment and effort. This will encourage further exploitation of the resources, more enterprises will have incentive to enter the fisheries, and exploit the fish stocks, and reap the possible profits. This will continue for as long as fishermen yield positive returns from their effort and investment. However, along this path fish stocks will be reduced and catch per unit of effort will decline. As time progresses, fish stock levels conceivably become reduced far below their maximum sustainable level and total catches are reduced in spite of more fishing effort. The common property nature of ocean fisheries is responsible for this behaviour of the fisherman. This explains why they overexploit the fish stock even against their better judgment. The most viable course of action is to try and grasp the biggest share possible while the resource is still large enough to yield some profits (Arnason, 1995).

This basically mirrors the course of events that the Icelandic fisheries went through. Even measures such as total allowable catches and restrictions did not have any effects. This is because the aspects of the fisheries are not changed. They are still common property after these measures have been implemented.

To digress, when the fishery authorities saw that their system was not working and that the biomasses for the most important demersal fish stock were not improving, they knew that some drastic measures had to be implemented. In 1984 a system of individual vessel quotas was introduced.[51] Not all fishermen believed in this system and a provision was added to the law that vessels which preferred to have effort restrictions could opt for that kind of arrangement. The Icelandic parliament, Alþing, passed a legislation in 1988 that all Icelandic fisheries would be in a general vessel quota system. In 1990 Alþingi passed a complete and uniform individual transferable quota (ITQ) system called the “Fisheries Management Act”. This legislation was considered controversial by both fishermen and the nation alike, and remains so to this day.[52]

The system is based on individual transferable quotas, meaning that they are permanent, perfectly divisible, and fairly transferable. The system works as follows: each year the fishery minister issues a total allowable catch (TAC) based on the recommendations of the Marine Research Institution (“Hafrannsóknastofnun”) and the ITQs represent harvesting rights in this total allowable catch (Arnason, 1995).

The initial allocation of quotas (later ITQs) varied between the fisheries. In the demersal fisheries the quotas were allocated, based on a three year catch history, most other fisheries followed similar lines. In the beginning most of the resistance came from fishermen, especially

[51] In first was this system intended only as an emergency measure to try and rebuild the fish stocks.

[52] This follows from the arguments of Libecap in chapter 3.

from the Westfjords (Vestfirðir) area fishermen. They felt that they automatically had a competitive edge by being closest to the some of the richest fishing grounds in Iceland, and that the quota system hindered this natural advantage.[53] Also, fishermen who had only recently acquired fishing vessels or whose vessel's had been in repair felt that the system was not fair to them because of their minimal catch history, or no-catch history, due to their vessels not having been operating in the years prior to the allocation of the quotas (Hannesson, 2006). Newspaper articles from that time have some very interesting headlines, such as: "A serious attack on our existence" ("Alvarleg aðför", 23. Nov, 1985), "We need a vacation from the quota system" ("Við þurfum að", 11. Sep, 1985), "The quota system inhibits the fishing abilities of men" ("Kvótinn er hemill", 11. Sep, 1985) and "The contraction in the fisheries will lead to lower employment or unemployment" ("Samdrátturinn veldur", 4. March, 1984).

Lately the controversies have concerned who owns the fish stocks and who should benefit from them. This begs some questions: has the quota system been successful? Has it reduced fishing effort? Have fish stocks recovered?

5.2 The achievements of the quota system

Before the introduction of the quota system the fishing industry was plagued with the common property problem. This led to fishing effort being excessive, fish stocks being overfished, and excess capital being invested in the industry. These investments were mostly unprofitable, i.e. beyond a certain point they did not lead to more productivity and revenue. Because of the common property nature of the fisheries, too much time and labour were being used in this sector. The fishing industry was Iceland's most important export industry throughout the 20th century. It was the main contributor to foreign exchange, this in turn led to more favourable exchange rates for the nation.[54] Unfortunately, this meant that every time industry went through difficult periods, the Icelandic currency was devaluated to keep the industry still running, and keep of the workforce employed. Because of the common property nature of the fisheries, this occurred quite often.

[53] The author does not think that these arguments are strong. The quota system does not reduce their natural competitive edge, if it does anything it enhances the advantage. The system should have allowed them to buy quota from those who could not benefit from the quotas in the same way they could, and exploit the rich fishing grounds even further.

[54] A more favourable exchange rate means that the Icelandic currency was stronger, thus leading to an increase in real wages.

Under the common property regime the fisheries do not reach equilibrium until profits are driven to zero, and the biomass of the fish stocks is driven to levels where the stocks are being overfished, as can be seen in figure 6 on page 48. These facts reveal that the fisheries were not employed on a socially optimal production path, one that maximizes the welfare and wealth of its people as was argued in chapter 4.

In chapter 3 it was reasoned that secure property rights influence economic activity and resource allocation by promoting the efficient accumulation of capital and division of labour mainly through five channels. The ITQs influenced the fisheries by reducing fishing effort and fishing fleets, contributed to fish stock protection, restored economic profits, and created a basis for a better overall utilization of factors in production.

The first and most important effects that the quota system had on the fisheries was in reducing the common property aspect of the fisheries, thus making them better managed and yielding profits. Figure 8 shows operating profits for both the fishing industry and fish processing industry from 1969-2013, in 2005 prices.

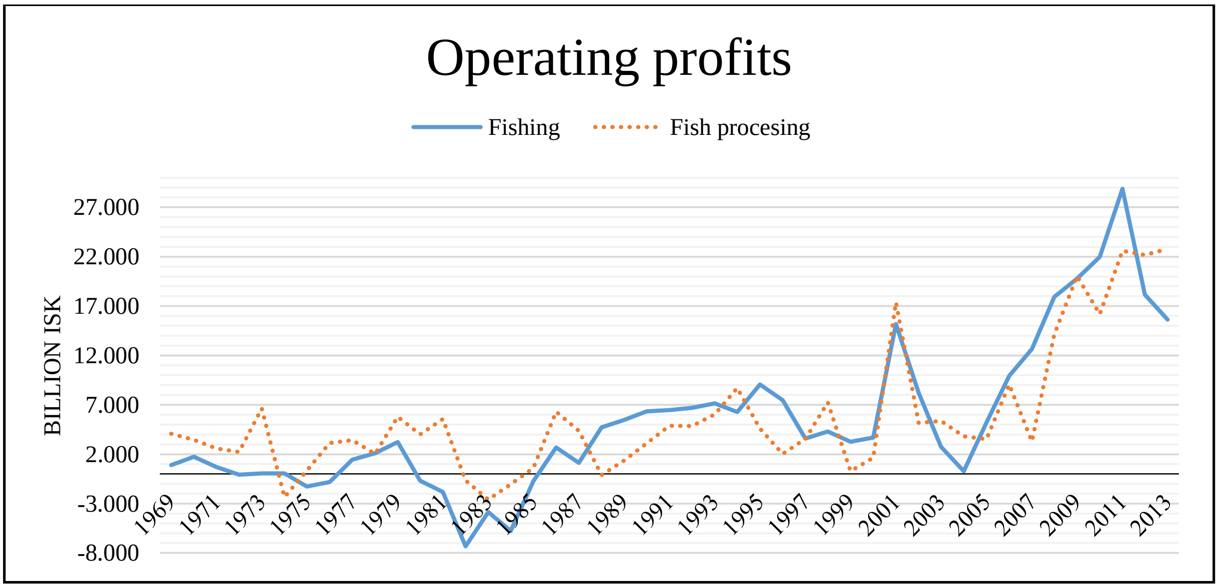

Figure 8. Operating profits.

Source: Statistics Iceland.

As can be seen from figure 8, the initial effects of the quota system in 1984 were to change negative profits to positive. In the years before the quota system, the fishing industry had, on average, operating losses which were 0.4% of revenue. After the implementation of the system, operating profits have been, on average, 10% of revenue (1985-2013) and 14% on average from

2000 and onward.[55]

The fish processing industry has also benefited from the introduction of the quota system. This has mainly occurred because, often the same owners who command the fisheries, run the processing plants. After the implementation of the quota system, more incentives to maximize profits from the scarce resources were created. A time co-ordination between landings, processing, and marketing needs has improved between the fisheries and the processing plants. Before the quota system the main incentive to fishermen was to fish as much as possible and not take into account that processing plants could not work all of the raw materials that came to them. Now-days this is planned before the boats go fishing, i.e. trawlers are advised how much to fish and when to come ashore to keep the fish processing plants at maximum performance.

The system has also been able to rebuild most of the fish stocks. Figure 9 shows the evolution of the biomass of cod from 1955 to 2014.

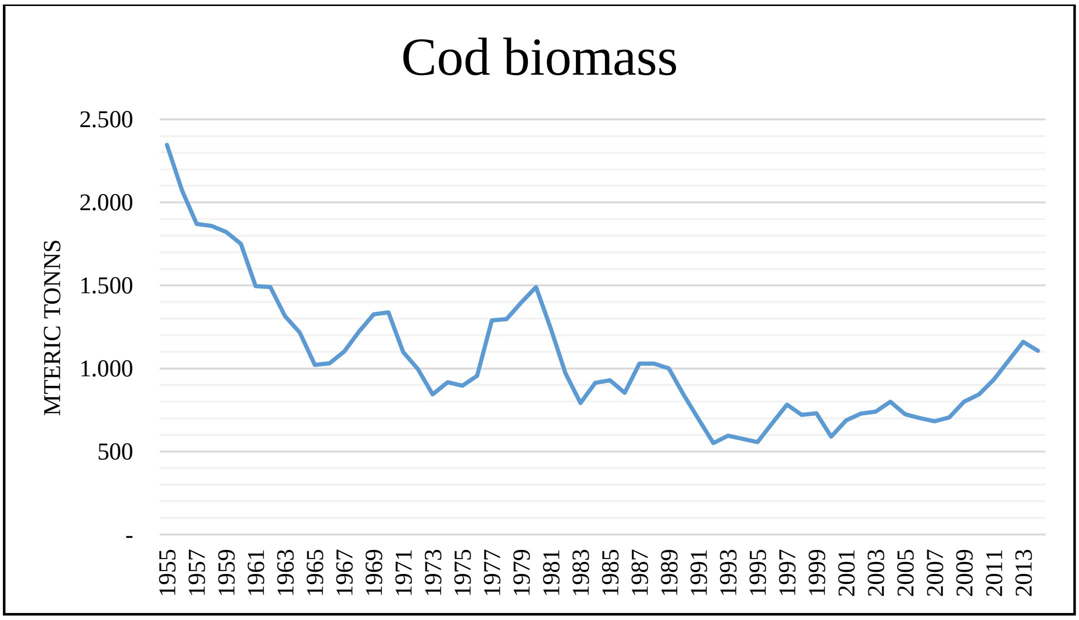

Figure 9. Cod biomass.

Source: Marine Research Institute.

As can been seen from figure 9 the initial effects of the quota system on cod biomass actually had no effect. The biomass kept on trending downward until it reached an all-time low in 1992, but since that period it has been improving. There are mainly three reasons behind this: the

[55] Remember that the ITQ system was introduced in stages, thus the property right quality has varied over time together with operating profits.

system went through many changes in its initial years and a dual quota system operated from 1986-1990 (the ITQs and an effort quota based system). The effort based system was much the preferred system; it meant that boats were allowed to fish for a certain number of days. This changed the incentives but little, and fishing effort increased during the years following 1984. Arnason (1995) showed that a structural break occurred in 1984 and fishing effort was reduced by 15% from 1983 to 1984 and by 6% in 1985. However, in 1986 it started to increase and by 1990 it had risen by 17% and reached a level similar to that of 1983. When implementing the quota system back in 1984, all boats that were smaller than 10 GRT (gross register tons) were exempt from the system. This meant that after a few years their numbers had multiplied, and by the mid-1990's their catch exceeded 20% of the total catch. In 2001 boats smaller than 10 GRT were finally included in the system.

From figure 9 it can be seen that the downward trend halted early in the 1990s and the biomass began to improve. Around the year 2001, when all boats had been introduced to the ITQ system, biomass improved further (Hannesson, 2004). The Marine Research Institution made errors when it estimated the biomasses, i.e. they kept on overestimating the fish stock and recommending a higher TAC than was sustainable. But in 2005 the model was revised, and since then their estimates have improved. This has resulted in better recommendations of TAC, which has yielded biomass to grow and fishing has been carried out in a much more sustainable way, as can been seen by the improvement of the cod stock since 2005 (Hagfræðistofnun, 2007).

Previously it was noted that investments should increase with better defined property rights because individuals can expect to reap benefits from their investments. In the fisheries it did not occur in this manner. When the fisheries were in open access and each individual could fish as much as he wanted, a race (competition) started between the fishermen. This happened because of the common property nature of the fisheries, where the effort of each fisherman reduces the output of the resource. As a consequence, each rational individual has an incentive to try to outwit the next individual and get the better of him in the competition. One way of accomplishing this is to invest in bigger and more powerful vessels. This is how the fisheries evolved; figure 10 shows how investments in the fisheries have varied from 1969-2013 in 2005 prices.

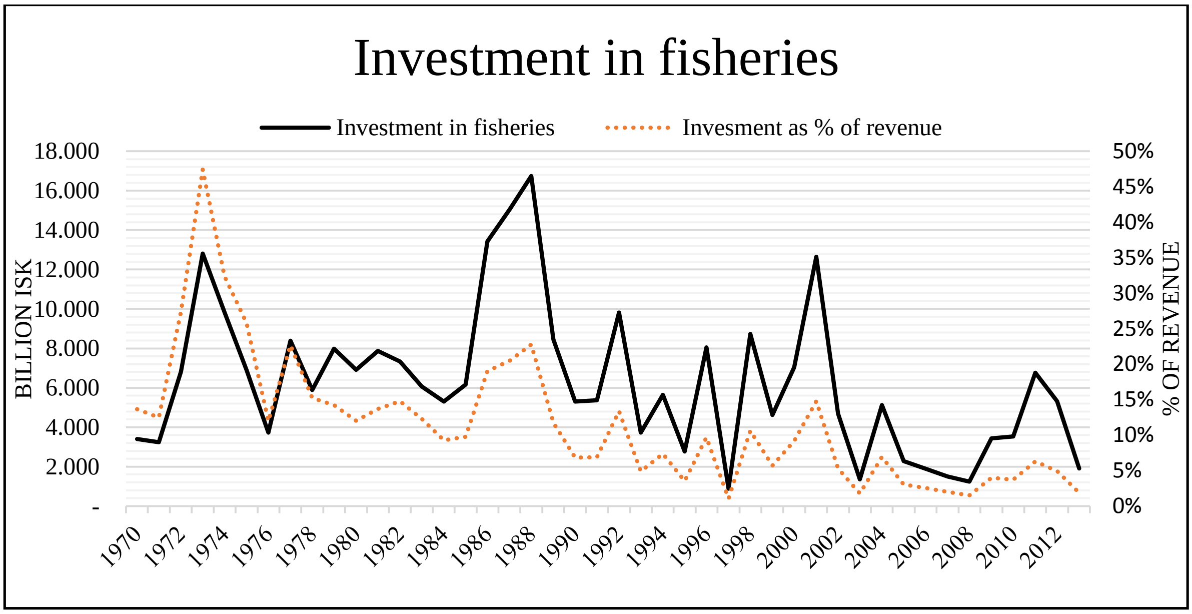

Figure 10. Investment in fisheries.

Source: Statistics Iceland.

When investments are examined in relation with revenue it can been seen that the relationship has been falling. Investments averaged 19% of revenue from 1970-1984, averaged 15% of revenue between 1985-1990, averaged 7.9% of revenue from 1991-2001, and have averaged 3.6% of revenue from 2002-2013. One of the main reasons for poor profits in the marine sector before the introduction of the quota system was overinvestment that yielded no additional revenue in the long run. With the introduction of the quota system, investments greatly decreased this is mainly because right incentives were introduced and no longer any needs to overinvest to try and yield some of the catches. The incentives were now to try and maximize the catches.

Previously it has been asserted that secure property rights will enable individuals to seek ever better ways of increasing production and the quality of output with new and cheap ways, i.e. incentives for experiment increase that will lead productivity to grow. Productivity is usually defined as quantity of output that is obtained from given quantity of inputs, and an increase in productivity means that more output is obtained from the same quantity of inputs. Before the introduction of the quota system, one of the main problems with the fisheries was low productivity. Higher degree of productivity is one of the main ways of increasing real wages and thus enhancing the standards of living.

A standard way to calculate productivity is the so-called total factor productivity (TFP) approach, which calculates the productivity of different factors to production (most often labour and capital) to total productivity. In the case of the fisheries a so called three factor productivity

(3FP) approach is implemented to calculate the productivity. This approach is much more suitable to measure productivity than standard 2TP as it accounts for the third factor in production, i.e. natural resource (fish stocks). Equation (5.2) yields the common way to calculate productivity (Arnason, 2000).

$$3FP_t = ln\left(\frac{Y_t}{Y_{t-1}}\right) - 0{,}5(w_{C,t} + w_{C,t-1})ln\left(\frac{C_t}{C_{t-1}}\right) - 0{,}5(w_{L,t} + w_{L,t-1})ln\left(\frac{L_t}{L_{t-1}}\right) - ln\left(\frac{S_t}{S_{t-1}}\right) \quad (5.2)$$

Where Y_t represents gross factor income on time t, C_t represents capital use on time t, L_t labour use on time t and S_t is an aggregated measure of fish stock which corresponds to unit landing prices in 2000.[56] $w_{C,t}$ and $w_{L,t}$ represent weights that capital and labour have in gross factor income and they sum up to unity. Due to lack of historic data, productivity could not be calculated for other industries than fisheries and industries in total for the period 1980-2013 (data for these calculations can be found in appendix C, in tables 6 and 7). Figure 11 shows the result of these calculations. The result is shown in a productivity index and both industries start with the index 100 in 1980.

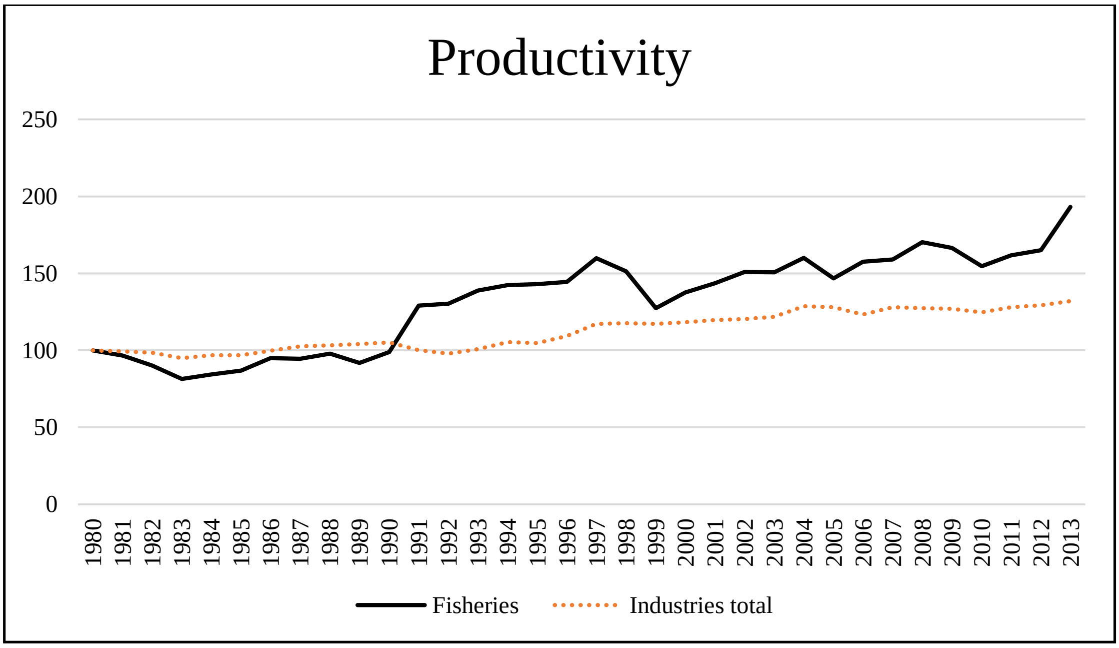

Figure 11. Productivity.

Source: Statistics Iceland, and author's calculations.

As figure 11 indicates, productivity has grown a great deal in fisheries, much more so than the average in other Icelandic industries. Productivity has grown on average by 3% in the fisheries

[56] The aggregated measure includes cod, haddock, saithe, redfish, Greenland halibut, herring, capelin and mackerel which captures on average over 85% of the catch values during the period that was examined.

from 1980-2013, and has only grown about 1% on average in other industries during the same period. Figure 11 indicates that productivity started to grow during the initial years of the quota system but did not take off until the uniform quota system was passed in Alþing in 1990. Productivity growth was negative by 2.5% on average from 1974-1984 (it was actually positive from 1984-1986 but with the dual quota system from 1986-1990 the growth halted and productivity decreased. Table 2 stresses average productivity growth between the fisheries and total industries during different periods.

Table 2. Average productivity growth between periods.

	1974-1984	1985-1995	1996-2006	2007-2013
Fisheries	-2,51%	5,27%	1,20%	3,18%
Industries total	0,90%	0,74%	1,54%	0,99%

Source: *Statistics Iceland, author's calculations.*

As indicated in table 2, productivity growth in the fisheries increased most between 1985-1995, i.e. when the quota system was being implemented and the fisheries were restoring the factors of production to their maximum use. The main reason why productivity growth slowed down in the fisheries from 1996-2006 is because the productivity of the fish stocks decreased during the period. The reason for that is mainly because of the errors made by the Marine Research Institution when they were estimating the fish stocks during those years. This resulted in excess fishing of what was sustainable and hence lower productivity. These results are similar to Agnarson (2011) and Arnason (2000).

On the whole, productivity in Iceland has grown rather slowly over the past few decades. There is no one clear answer to this, but it is the author's opinion (one amongst many) that it can be traced back to the lack of competition on the domestic market, plus few, if any, industries are competing in international markets. This leads to less incentives for innovation, because the few companies competing on the domestic front have satisfied their needs. People tend to be risk averse when there are gains involved, and as such, domestic companies don't want to risk financial losses for a possible larger share of the market. Those industries and companies that are competing on international markets tend to be the most productive. This includes the marine industry and companies like Marel, Össur, Skaginn and Hampiðjan to name a few.

It is quite clear that the introduction of the ITQ system had positive effects on the operational side of the fisheries, and has yielded more profitable investments. This has in return greatly improved the productivity of the marine sector, i.e. it has helped in social optimal use of factors in production that has helped to achieve maximum social welfare. Since the introduction of the quota system in 1984, real wages per individual have increased by approximately 178% in the fisheries sector. However, it has only increased approximately 80% for other industries during the same period. On the whole, this contrast can be explained by the difference in productivity growth, i.e. productivity grew much more in the fisheries, and thus real wage grew more. In the period preceding the quota system, real wages only grew by 44% in the fisheries and 30% in other industries. This is according to what was predicted in chapter 3 and more precisely in chapter 4, i.e. real wage should grow with better quality of property rights. It is important to note that more growth in real wages in other industries is not only linked with better defined property rights in fisheries but to many other aspects in the economy. A rough estimate has yielded that real wages would have been 2% lower on average in Iceland during the period 1984-1994 if the quota system had not been implemented, and 1% lower on average from 1984-2013. The reader should be mindful of these calculations as the mechanism underlying the model of these calculations are extremely simple. These results should only be regarded as indicators of the effect that the quota system had on real wage.

Labour use in the fisheries sector was reduced following the implementation of the quota system. In 1984, 4.8% of the workforce was employed in the fisheries. Because of the dual quota system that operated from 1986-1990 the ratio of individuals employed in the fisheries rose, and in 1990, 5.7% of the workforce was employed in the fisheries industry. Following the legislation passed by Alþingi in 1990, the ratio dropped and the following year 4.5% of the workforce was employed in the sector, and only 2% in 2013. This evolution can be seen in figure 12.

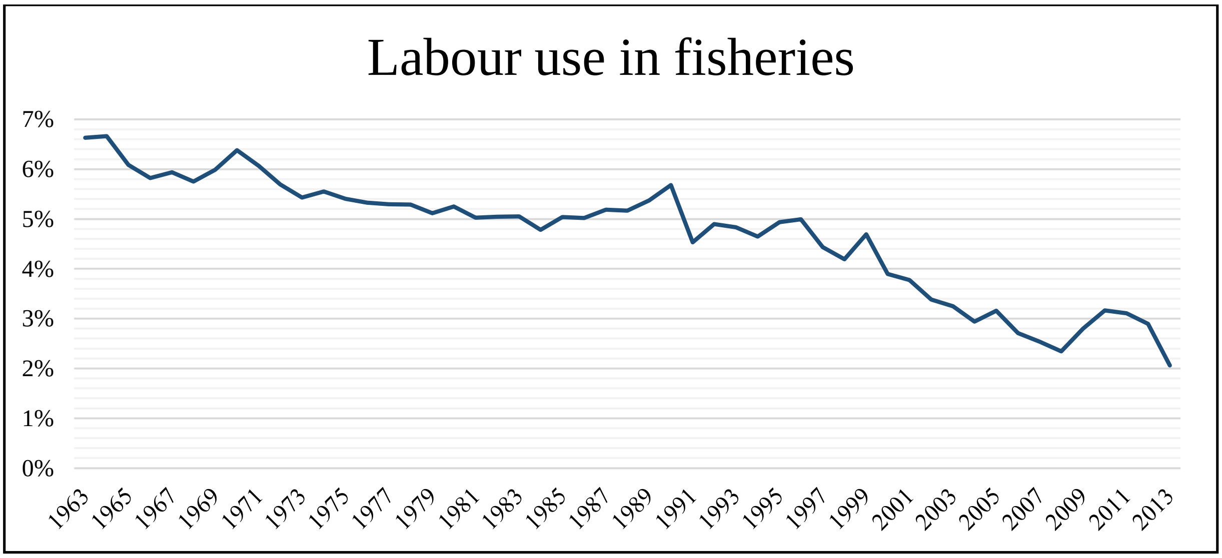

Figure 12. Labour use in fisheries, 1963-2013.

Source: Statistics Iceland and Hagskinna.

As can be noted from figure 12 the ratio of labour employed in the fisheries had been falling on average by 1.2% from 1963-1984 and on average 5.7% of the workforce was employed in the fisheries sector during that period. After the implantation of the system the downward trend doubled, and has been falling on average by 2.4% ever since. On average 3.8% of the workforce has been employed in the fisheries from 1990-2013.

The drop in labour use in the fisheries industry meant that labour was free to pursue other activities, and thus not be stuck in an unprofitable industry. This was mostly true of the marine sector before the quota system. It can thus be regarded that the excess labour that was employed in the industry was not yielding anything to society, as they were in part responsible for the low or negative profits in the industry. With the introduction of the quota system this was not a problem anymore and the combination of the labour force became more optimal, thus enhancing social welfare.

The demand for people with some form of higher degree than the level of secondary education has increased in the marine sector. This increase has come about because of higher incentives for innovation in the sector to maximize the value of the quotas. This innovation is one of the main causes for the productivity increase in the sector since the quota system. The demand for ever more innovation has become the breeding ground for high tech industries in Iceland. This has brought about the rise of big companies such as Marel, Skaginn, Promens, Héðinn and Hampiðjan. In 2013 there were 1.000-1.500 employed in high tech companies providing the marine sector with equipment. About 20% of these companies have revenue that exceed 1 billion ISK on a yearly basis and do 80-90% of these revenue come from exports. In 2013 the exports were approximately 8 billion ISK from this industry or 1.6% of exports that year (Íslenski Sjávarklasinn, 2013). These high tech industries provide the marine industry with equipment to produce better quality products, increase output and make it possible to work every inch of fish that is brought to land. Thus, productivity is increased. Also, the equipment has yielded a demand for vocationally trained individuals to run and look after this equipment. All of this comes together to increase the demand for social capital.

Furthermore, the ever higher values of the quotas and the incentives to fully utilize fish products, has yielded in an ever-growing bio-tech industry in Iceland. These companies are, to name but a few: Kerecis, which manufactures products to treat chronic wounds and works closely with the USA army. Primex which is the global leader in producing and supplying pure chitin and chitosan derivatives and Zymetech who are the global leaders in therapeutic application of marine-derived enzymes.

It can be concluded that the quota system has had an indirect effect on the social structure of the Icelandic economy and has played a role in enhancing its social capital. The ratio of university employed labour has increased greatly from 1990, and in 1991 approximately 10% of the labour force was with a university degree. It had reached 15% in 2000 and by 2013, the ratio had reached 36%. There is little proof, if any, for causality between the introduction of the quota system and this increase. However, it is not possible to ignore these figures entirely and reject that the marine sector has not had an effect on this increase.

A final effect that the quota system has had on the fisheries sector and the economy is that of creating live capital, just as de soto (2000) contended that property rights have. The only way that property can contribute to welfare is the opportunity to work live capital from them. Live property can thus be used to create value for its owner in a variety of different roles. Live capital contributes to society because it creates the opportunity to create new valuables from them, i.e. they can be used as collateral for investment (de soto, 2000). In defining property rights in the form of ITQs, the fish in the fishing jurisdiction became live capital. Because the quotas are transferable, this creates a market for them and a market price. This has allowed quotas to be transferred to the most efficient fishermen. Also, this has meant that all the fish, and the right to harvest them (quotas) can be regarded as capital, thus expanding the capital assets of the nation and acting like a springboard to achieve higher economic growth. To have more capital is one way of enhancing economic growth and welfare.

The quotas actually meant that fishermen could use them as collateral to obtain financial capital through investments, thus expanding the capital assets even further. These investments also meant that productivity increased. Therefore the efficiency of the fisheries and the economy also increased. In a paper by Arnason (1990) it was shown that the market price of the quotas will reflect the present value of expected profits from holding the quotas, thus a good predictor of future profitability and the economic value of the fisheries. In a study done by Hagfræðistofnun (2010) the values of the permanent quotas, from the introduction of the uniform quota system in 1990, were estimated. These estimates show that quota values increased a great deal during the initial years of the system, figure 13 shows their evolution from 1991-2011.

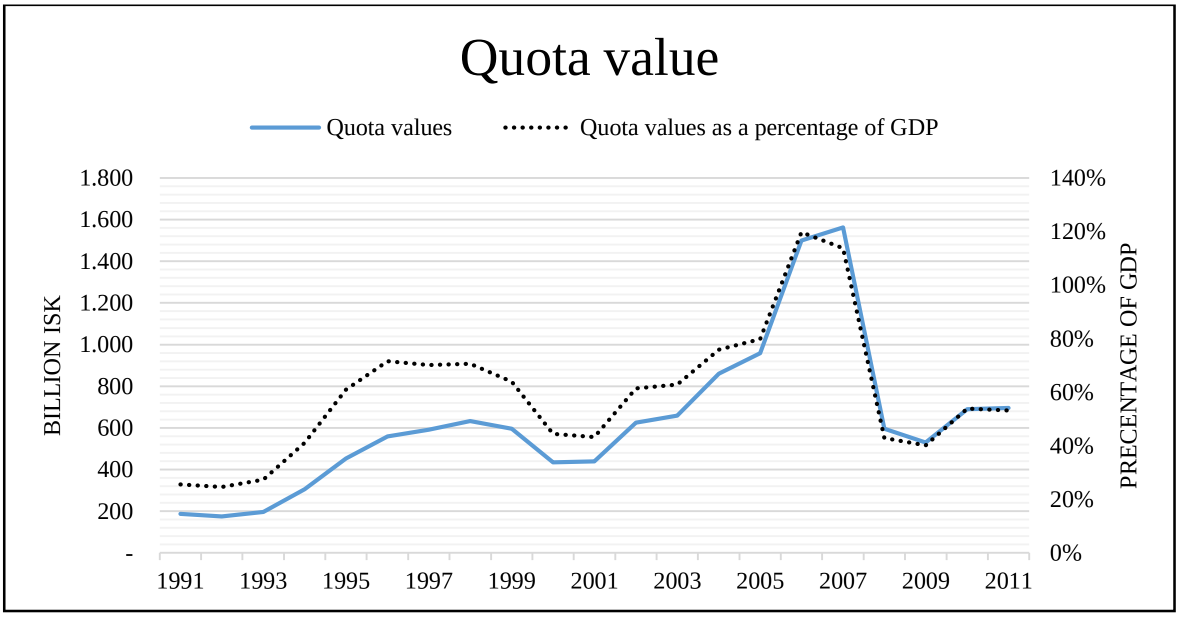

Figure 13. Quota values.

Source: Hagfræðistofnun (2010), The Directorate of Fisheries, and author's calculations.

In 1991 the quota value was 187 billion ISK (in 2007 prices) which yielded approximately 25% of GDP, as figure 13 also indicates. The value of the quotas rose sharply in 1994 and 1995, or approximately 50% both years, i.e. from being 195 billion ISK to 570 billion ISK which approximately yielded 65% of GDP. Following the discussion of introducing boats smaller than 10 GRT to the quota system in 2001 the value of the quotas dropped around 1999-2001. However, they rose sharply again and stayed high until 2008. With the financial crash of 2008, the government started to stir in the quota system, which resulted in greater uncertainty for quota holders and what the future would hold. Thus, the value dropped drastically in 2008 and have stayed relative low compered to the years before.

Arnason (2008) has argued that the ITQs have created new wealth in Iceland. Of course the underlying natural resource existed before the introduction of the quota system. However, because of the common property nature of the fisheries before the implantation of the ITQs, they yielded little or no economic wealth. As has been argued throughout this thesis, property rights, and in the case of Iceland, the ITQs, change the incentives of fishermen who are employed in the sector. Fishing effort and fishing fleets have been reduced, fish stocks have improved and the co-ordination of supply and demand of catches have greatly improved. This has greatly improved the economic flow from the fisheries. Also, the ITQs created marketable assets, i.e. the value of the fisheries could be represented on the market (Arnason, 2008).

As stated above, the implantation of the ITQs and their wealth, is living capital. This capital has been used as a foundation to raise financial capital and has contributed to other sectors of economic activity. This can be verified when it is observed that most of the original quota shares have been traded, and have changed hands more than once (Hagfræðistofnun, 2010). Thus many of the initial and latter owners of the quotas have realised their value and sold them and moved the equivalent financial capital to other industries. Therefore, by creating living capital, the ITQs have greatly increased marketable wealth and greatly helped in contributing to one of the longest economic growth periods in the modern economic history of Iceland. Figure 14 shows the evolution of GDP in real terms (2005 prices) from 1970-2013.

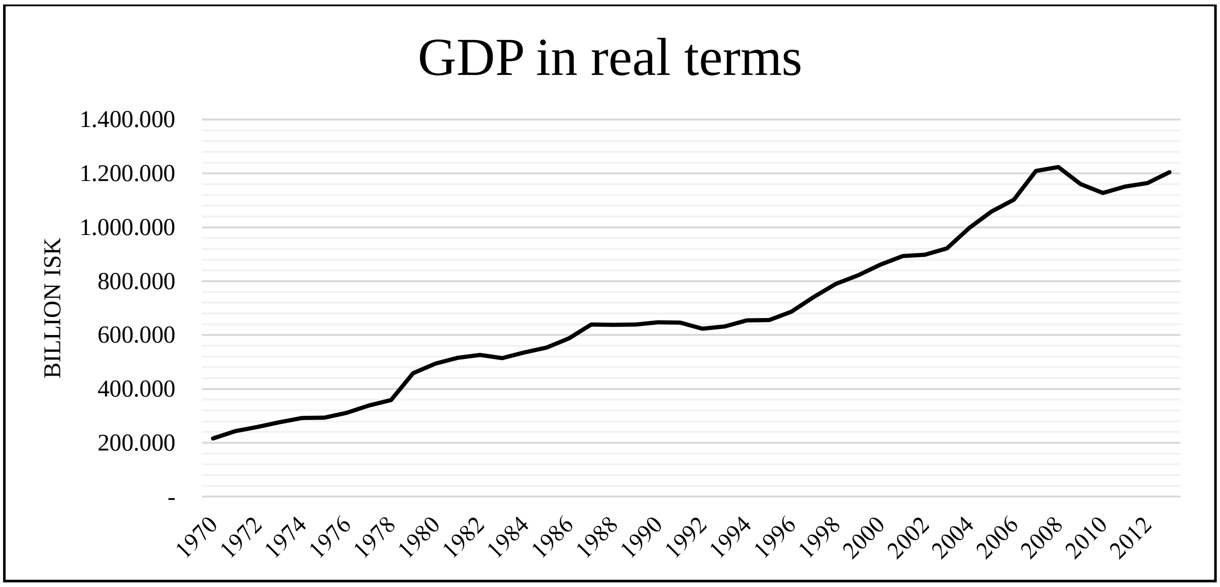

Figure 14. GDP in real terms.

Source: Statistics Iceland.

Since the establishment of the ITQ system the Icelandic economy has, on average, experienced more economic growth than the EU, UK, USA and the OECD countries. From 1991-2008, real economic growth in Iceland averaged 3.7%. During the same period, average economic growth in the EU, UK, USA and OECD countries yielded: 2.2%, 2.4%, 2.9% and 2.4%.[57] Also, GDP per capita rose more, on average in Iceland, or 2.4%. On average, in the EU, UK, USA and OECD countries, GDP per capita rose by: 1.9%, 2%, 1.7% and 1.6%.

Of course, this does not prove a causality relationship between the wealth created with the ITQs and economic growth, but there is some evidence that supports this theory. Firstly, traditional economic growth theory, as described in chapter 2, predicts that more capital will yield more economic growth and GDP per capita. Secondly, by creating living capital that could be used as collateral meant that more financial capital could be raised, i.e. gross capital

[57] The period 2009-2014 is not stated because of the economic recession that hit the world in 2007-2008.

formation (investments) increased. It was argued in chapter 2 that investments are necessary to achieve economic growth. This is because capital deteriorates and needs to be replaced. Also, investments most often lead to productivity growth, which was the other requirement mentioned as necessary to sustain long-term economic growth. The numbers support this theory quite well. On average, from 1991-2008 investments in Iceland increased annually by 8.5%, but from 1970-1990 they only increased by 4.5%. In the EU, UK, USA and OECD countries, capital formation, on average, only increased annually from 1991-2008 by 2.5%, 3.1%, 3.5% and 2.5%. Thirdly, the timing and correlation of the ITQs wealth and real GDP is strong. As the ITQs gained more marketable wealth, note figure 13, it can be seen that GDP took off at a similar time (around 1994), see figure 14. Fourthly and finally, by the refashioning of the economic structure of Iceland, especially that of the financial sector. The expansion of the financial sector can be explained in part by the wealth that was created by the ITQs (Arnason, 2008 and Worldbank).

The implementation of the quota system cannot take all of the credit for the high rate of economic growth Iceland experienced during 1991-2008. The Icelandic economy experienced many changes to its economic structure in the early 1990s. In 1992 Iceland joined the European Economic Area (EEA), the capital controls which had been around for over sixty years, were lifted in 1994, plus many state owned companies were privatized during the same period. All of these structural changes also played a large role in the sustained economic growth and welfare increase. However, as was noted above, most of this growth was driven by investments, and the subnational part of the new financial capital was derived from the new wealth that was represented by the ITQs. In their extensive report entitled “Where does the money come from”, Porters and Baldursson (2007) asserted that the equity used to sustain Iceland’s rapid growth came mainly from the privatization of the stated-owned banks of the early 1990s and from the new wealth created in the fisheries by ITQs.

The predictions about the impact of property rights and their impact on economic growth and welfare which were made in chapters 2, 3 and 4, can confirm mostly the evolution of the Icelandic economy, and explain why Iceland has experienced higher rates of economic growth than neighbouring countries. The increase in welfare and economic growth in Iceland is mostly thanks to a better structure of the marine sector, which came about because of the quota system. This not only effected the sector, but also, as has been reflected in the above examples, had indirect effects throughout the economy.

6. Sunken billions?

In chapter 5.2 it is contended that the implementation of the quota system is one of the main reasons for Iceland's economic growth success during the period between 1991-2008. Even though the quota system has had extremely positive effects on Iceland's welfare and economic growth, it has always been highly controversial. Initially the fishermen who were employed in the sector during its implementation, reacted negatively. However, most of the fishermen eventually realised the positive economic consequences of the system and its effects on the fish stocks. For the past decade or more, the controversies have mostly been about who should gain from the fisheries, the fact that in the beginning quotas were given away, and the huge amount of wealth that was transferred. Article one in chapter one of the Fisheries management act (2006 nr. 116 10. ágúst) states:

> "Fish stocks in Icelandic waters are the common property of the Icelandic nation. The objective of the act is to promote the conservation and efficient utilization of the fish stocks and ensure stable employment and settlement in the country. Allocation of fishing quotas under this act does not confer ownership titles or irrevocable control of fishing rights for individuals."[Translated by author]

This provision has been on the nation's lips ever since it was confirmed in the Icelandic parliament, Alþingi. Icelandic voters have requested that the holders of the quotas uphold this provision, and that Alþingi makes sure that the wealth the quotas generate are redistributed back to them. Since it became law, lawyers have argued about its meaning. Some people have argued that there is more to this provision than meets the eye, and that the words "common property of the Icelandic nation" do not mean that it is the property of the nation (Líndal, 1998). Líndal argued that without further restriction, the nation cannot be regarded as having ownership title of the fish in the jurisdiction, in the form of traditional legal rights.[58] Others have argued, including the author, that there are two objects in the provision which conflict; that they can never simultaneously work together. These objects are: the ensuring of efficient utilization of

[58] Líndal and co-author take an example of the meaning in law number 59/1928 provision 4, regarding the conservation of Þingvellir. That law states that the protected area is under the protection of Alþingi and is the property of the Icelandic people. What does the "property of the Icelandic people" mean? The law states that the property cannot be sold and that the nation is guaranteed access to the site. The administration of the conservation area is in the hands of parliament and a committee that parliament has chosen. However, neither parliament, the committee, nor the nation, has the authority to act as an owner.

fish stocks and the ensuring of stable employment in settlements all over the country. Together they will only exceed in reducing the economic benefits of the system.

It is the author's opinion that the controversy that has surrounded the act is mainly caused by how poorly the act is defined, and that the Icelandic nation is not well enough informed about the economic characteristics of the system. Particularly so, because it appears that many do not understand how the system has created wealth from a resource that was not generating any wealth before the implementation of the quota system. Also, it seems many do not understand how the system ensures efficient allocation of factors in production that enable maximum wealth to be created from resources which will maximize social welfare.

Previously, the author has proposed the main characteristics of property rights can be summed up in security, exclusivity, permanence and transferability (see chapter 4). Because of the debate that has surrounded the system, transaction costs have been too high and thus these characteristics have not been of the highest quality. This has resulted in the ITQs not having been of high enough quality, which in turns has led the fisheries to not being employed along the socially optimal production path. If not for these controversies, it can be argued that the fisheries would have achieved more profits and wealth generation for the nation, which would have resulted in even more economic growth and welfare than has occurred during the last two or three decades.

By using optimal control theory it is possible to calculate an approach of what such a reduced security has cost the nation. Likewise, it is possible to calculate the difference in discounted profits by following the system at different periods. The model used is the same as Hagfræðistofnun (2007). It is a simple model, but theory and experience have shown that it is a credible model, and that it highlights the main features of both the bio- and economic aspects of the fisheries. The main equations of the model are:

$$\dot{x} = G(x_t) - q_t \tag{6.1}$$

$$C(q_t, x_t) = k \cdot \frac{q_t^{\delta}}{x_t^{\varepsilon}} + fc, \tag{6.2}$$

$$P(q_t) = p_t \tag{6.3}$$

$$\pi_t = P(q_t) \cdot q_t - C(q_t, x_t) \tag{6.4}$$

Where x represents fish stock biomass, q the flow of harvest and p the price of landed fish. Equation (6.1) describes the evolution of the fish biomass, equation (6.2) is the cost function and (6.3) represents the inverse demand function for landed fish, and finally, equation (6.4) is the profit function (Hagfræðistofnun, 2007).[59] The form of the functions and their coefficients are shown in appendix B.

The objective is to discover an optimal time path for harvest that maximises the following functional (6.5) and then calculate the optimal feedback rule:

$$\underset{\{q\}}{\text{Max}}\, V = \int_0^{\infty} (P(q_t) \cdot q - C(q, x)) \cdot e^{-rt}\, dt, \tag{6.5}$$

$$subject\ to: \dot{x} = G(x) - q,$$

Where V is the value functional and r is the discount rate. The corresponding Hamiltonian functional to this equation and the necessary conditions for solution are:

$$H = p \cdot q - C(q, x) + \mu \cdot (G(x) - q) \tag{6.6}$$

$$H_q = p - C_q - \mu = 0 \tag{6.7}$$

$$\dot{\mu} - r \cdot \mu = C_x - \mu \cdot G(x) \tag{6.8}$$

Where μ is the shadow value of the fish stock. A formal presentation of the following problem and a derivation of it are presented in appendix B.

This thesis only views the cod fisheries. Trying to calculate optimal time path of harvest for all the fisheries would be impracticable here.[60] The cod fisheries have always been Iceland's most important fisheries and have yielded on average 37% of catch value from 1984. Thus, calculating the optimal harvest for the cod fisheries and comparing them with the current production path can give a good estimate of what this uncertainty has cost the nation, i.e. "sunken billions".

By solving equation (6.5) it is possible to calculate the optimal feed-back rule for the Icelandic cod fisheries. The solution yields that optimal equilibrium harvest should be 321 thousand tons a year. By harvesting 321 thousand tons a year, the cod biomass would be 1197 thousand tons a year. The feedback rule is as follows:

$$q_t = \begin{cases} -402{,}498 + 0{,}0005 \cdot x_t^2, if\ x_t \geq 892{,}722\ thousand\ tons. \\ 0 \qquad\qquad\qquad\qquad\quad , if\ x_t < 892{,}722\ thousand\ tons. \end{cases} \tag{6.9}$$

By adhering to this optimal catch rule, from 1984 onward the fisheries would have followed the harvesting path shown in figure 15.

[59] The profit function consists of net revenue minus operation costs and does not consist of depreciation, interest expense and taxes, i.e. it is EBITDA.

[60] For example there is not enough data on all the fisheries.

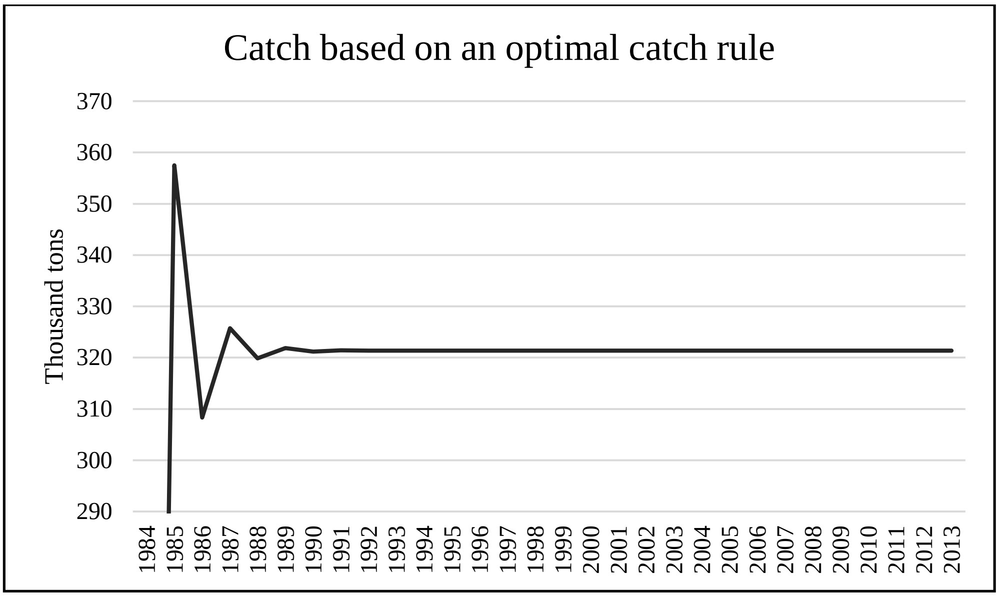

Figure 15. Catch based on an optimal catch rule.

To build up the fish stock, catch would have necessitated being around 19 thousand tons in 1984 compared to the 382 thousand tons it actually was. The following year the catch would have been much more, as is indicated in figure 15. The fisheries would have reached equilibrium around 1990. The optimal catch rule allows the fishing rate to be 26.8% of the fish stock biomass in equilibrium. Compared to the 20% fishing rate that the Marine Resource Institution allows for these days.

Equation (6.5), gives the optimal path of the cod fisheries and the profits they would have yielded on that path.[61] By comparing them with actual profits from the cod fisheries during the same time, it is possible to estimate the "sunken billions" that have occurred.[62] The uncertainty, among other things, has reduced the quality of the property right and yielded in the fisheries not being employed on the optimal production path. Table 8 in appendix D yield these results. The main result from the calculations is that approximately 598 billion ISK (in 2005 prices) in profits have been lost since 1984, i.e. the cod fisheries could have yielded an extra profit of 598 billion ISK if the fisheries had operated on the optimal production path since 1984.[63] In 2014 the profits from the cod fisheries were 12 billion ISK less in real terms which accounts for

[61] That is to say if the fisheries are explained by the above profit function.

[62] Actual profits from the cod fisheries are calculated by using the profit function (6.4).

[63] Of course there can by other reasons for why the fisheries have not been employed on the optimal production path. For example, the Marine Research Institution errors in estimating the fish stocks. But from the discussion in chapter 4 this seam just as reasonable reason as any other.

approximately 1% of GDP that year, i.e. if the fisheries had been employed on the optimal production path. On average, the sunken billions have accounted for 2.2% of GDP from 1984-2014.[64] Table 3 stresses the results for the year 2014.

Table 3. Main results for 2014.

	Unit	Actual	Optimal	Difference
Biomass	Tons. Thous.	1.106	1.197	91
Catch	Tons. Thous.	240	321	81
Profits	Million ISK	21.156	33.159	12.003

Source: *Author's calculations.*

As can be seen in table 3, the catch in 2014 was 81 thousand tons less than the optimal solution predicts, and the biomass has not been able to grow to the optimal size. In chapter 4 it was argued that taxation would increase the marginal stock effect and thus, the biomass level.[65] The impact this has on the fisheries includes the property right holder diverting from the socially optimal production path, and slower harvest. In recent years the fisheries have been heavily taxed, this in part explains why the fisheries have not harvested more. Heavy taxation has been justified by arguing that the fisheries should pay back some of the profits to the nation. As the above solution indicates this regime has been socially costly; reducing the wealth of the programme, and the welfare of society. Such heavy taxation is, of course, not the only pest that plagues the fisheries.

These results strongly indicate, and show, the importance of having well defined property rights so that producers can recognize the true value of the resource. And therefore employ factors in production in the most efficient way. The uncertainty that has surrounded the system has reduced the security character of the property right, and has thus prevented the fisheries from reaching the optimal production path.

To support this theory the author was in contact with Kristinn V. Jóhannesson who was the chairman of the board at Síldarvinnslan í Neskaupstað (SVN) an Icelandic fishing company, from 1980-2005, and Adolf Guðmundsson who was the owner of Gullberg, a fishing company. Guðmundsson was also chairman of the board at Landsamband íslenskra útvegsmanna (LÍÚ) from October 2008 to October 2014. LÍÚ was an association which protected the interests of

[64] One can imagine that GDP could have been on average 2.2% more, and real wages would also have increased also. Thus, welfare would have been enhanced even more.

[65] The biomass has not reached bigger levels partly because of Marine Research Institution misjudgements when estimating fish stock.

Icelandic companies in the marine sector. The association was disbanded in October 2014 and a new organization was formed called Samtök fyrirtækja í sjávarútvegi (SFS), which together with new ones, has the same goals as LÍÚ. Jóhannesson informed the author that the uncertainty that surrounded the system resulted in the impossibility of making long term plans, and that every time that there were parliamentary elections the quota-holder stood at a crossroads because they didn't know if they would still be a holder of quotas, or whether the system would change. This can be understood as discounted profits were only ever maximized for a period of four years or so. Guðmundsson agreed with this statement but added that the main debate around the system began at the same time the fisheries started to yield profits, and the quotas became valuable in and around 1993. He also said that during the period 2003-2008, when the financial sector was expanding, the controversies around the system died down and the sector was able to operate without any interference. Following the recession which started in October 2008 and to this day, the controversies around the system have escalated. From the above results, plus the arguments made by Jóhannesson and Guðmundsson, the theory that reduced security and permanence reduce the efficiency of fisheries, lower profits and operate on a non-optimal production path, is supported (Kristinn V. Jóhannesson and Adolf Guðmundsson, personal interview, March 9, 2015 and April 1, 2015).

The same methodology can be used to show how much it can cost to delay employing an optimal fishery management system. Actually, it would not have been possible to engage a quota system until 1975, when the fishery jurisdiction was expanded to 200 miles, and all the foreign fleets left the fishing grounds. Except for capelin and mackerel, most of Iceland's important fish stocks reside within the 200 mile jurisdiction. As discussed above, it would have yielded little to implement a quota system before the 200 mile limit was enforced. Following this, the fisheries authorities could better monitor the fish stocks, and those who were operating in the industry. Or, at least this was the theory, unfortunately, we now know that this didn't occur. The fisheries were highly unsustainable following expansion of the jurisdiction, as the Icelandic fishermen filled in the void left by the foreign fleet and fishing effort increased. By using the same methods as before, and on condition that they would have been on the optimal harvesting path, it is possible to calculate what it cost Iceland not to implement a quota system in the cod fisheries earlier. Two different dates are calculated: 1975 and 1980, i.e. the difference between the discounted profits from implementing the quota system in 1975 from that of 1984, and 1980 from that of 1984 is calculated.

If a quota system in the cod fisheries had been implemented in 1975, they would have yielded

311 billion ISK more in discounted profits than if they had been implemented in 1984. The cod fisheries would have yielded 179 billion ISK more if they had been implemented in 1980. These results are based on the optimal production path from 1984 and onward. They do not show the difference between what occurred in the first place and how high the profit could have been if Iceland had taken up the quota system earlier. But the results can be regarded as good indicators for how much the cost can be in delaying to employ an efficient fishery management system. As the result reveals, by just delaying four years, profits can be reduced by as much as 179 billion ISK.

Other results indicate that the quota system has been improving over the years. This can been seen if the optimal catch rule is employed from 1995, 2000, and 2005, and the discounted profits are compared with what actually happened. The results from these calculations yield that the difference between the optimal production path and the actual production path have been decreasing. These results are shown in table 4 below.[66]

Table 4. Discounted profits between periods.

	Unit	**Actual**	**Optimal**	**Differance**	**Current as % of optimal**
1995	Million ISK	342.147	595.961	253.814	57.41%
2000	Million ISK	401.091	602.396	201.305	66.58%
2005	Million ISK	469.563	605.669	136.105	77.53%

Source: *Author's calculations.*

As indicated in table 4, the difference between the optimal production path and the current production path has been falling. During a ten year period the difference between the optimal production path and the current path has reduced by approximately 117 billion ISK. These results can be regarded as indicators that the fisheries are becoming more optimal as time progresses.[67] There is though, still a long way to go before the fisheries will be employed on the optimal path, thus ensuring the wealth and welfare of the nation. For example, in 2014 the difference was 12 billion ISK and current profits yielded approximately 63% of the optimal solution profits. This can also be supported by the idea that the quota values dropped drastically in 2008 and have been reluctant to raise since then. The reason for this can most likely be summed up in the measures undertaken by the government in recent years that has increased

[66] Further information can be found in appendix D, tables 9 – 12.

[67] The resistance to the quota system has been growing and the author wonders if this will not only stop the fisheries from converging to the optimal path as has been the case, but whether the trend will be reversed.

uncertainty.

The reader should bear in mind that these results are all based on the cod fisheries being explained with the above profit and biomass growth functions. Also these results have not been simulated with conditions of uncertainty, i.e. the cod biomass could have developed differently, which would change the results. The most common way to handle this is with a so called Monte-Carlo simulation. This thesis does not employ such an approach. However, it is believed the results would most likely have been of a similar distribution to those of the above model.

This chapter clearly indicates how important it is to ensure that property rights are of the highest quality, and also points to how the debate has reduced the quality of the regime. Debates can increase uncertainty around rights, and that may reduce the security of a title. This will lead to the title holder desiring short term profits over long term profits. The only action that these debates have accomplished is in reducing the efficiency of the fisheries, and thus reducing the possible profits for the whole nation.

7. Conclusion

The thesis has explained the evolution of the Icelandic economy from World War II and what has driven its "boom and bust" cycles. It explains how the fishery sector is the basis of these cycles, and how a better defined property right structure in the fisheries, with the highly controversial fishery management act, has reshaped not just the sector but the economic structure of the Icelandic economy. Plus, it has discussed how the controversial debate concerning the fishery management act has actually reduced the prosperity and success of the fisheries and with it, the prosperity and success of the Icelandic economy and its people.

The thesis raises the question of how nations have accumulated so much wealth over the last two centuries and how they have reached such high standards of living. Neo-classical growth theory sheds light on some of these aspects and explains the growth of nations reasonable well. Nonetheless, growth theory sheds little light on what has driven this increase in growth and why it has been so different between countries. However, property right theory explains how this has accrued.

Property rights have a direct effect on the incentives of individuals, guiding them on the social optimal production path that maximizes the wealth and welfare of nations.[68] Property right theory largely explains why the western world has been able to enhance welfare, while other nations have been left behind, and why the actions of the western world have not been able to enhance the standards of living in the third world nations, as suggested by neo-classical growth theory. The actual answer lies in poor institutional structure of third world economies, and among other things, ill-defined property rights.

Well-defined property rights act like springboards for the economy to enhance their welfare and wealth accumulation. Only with well-defined property rights can nations expect to see their standard of living improve.

Iceland has experienced many cycles in its economy since World War II. Most of these cycles are explained by the performance of the marine sector. Recent research has shown that the marine sector is a so-called base industry in Iceland. It explains why the economy has gone through these cycles when the performance of the marine sector has been positive or negative. Taken that the fishing industry is a base industry, it is important that it is managed in a manner that ensure maximum wealth generation in a sustainable way.

[68] In other words, what comes closest to the social optimal path. With well-defined property rights individuals will always have incentives to do their best in reaching the social optimal path.

The quota system was implemented to ensure that the fisheries would be conducted on a sustainable basis. This act has proven to be highly successful. Not only has the performance of the marine industry improved but the act has had positive indirect effects throughout the economy and acted like a catalyst for the nation to achieve higher economic growth rates and welfare.

Since the introduction of the quota system, operating profits in the marine industry have greatly improved and gone from being, on average, negative before 1984 to being, on average, 10% of revenue from 1985-1999, and 15% of revenue from 2000. The fish stock biomass has improved for most of the species. The cod stock biomass has increased by approximately 100% since it was at an all time low in 1992. From when the quota system was refined, in 2001, most other demersal fish stock biomasses have been improving. Productivity has improved greatly in the industry, or on average, about 3% on a yearly basis since 1984 and much more than other Icelandic industries have managed (on average 1% on a yearly basis). This productivity growth has enabled real wages to increase significantly. In the marine industry, real wages have grown approximately 178% since 1984. Estimates yield that if the quota system had not been implemented, real wage in Iceland would have been on average 2% less from 1984-1994 and 1% less on average from 1984-2013. The establishment of the quota system also meant that it created live capital. This capital enabled a large amount of financial capital to be raised and used in other economic activities. This live capital appears in the values of the quotas. In 1991 they were approximately 26% of GDP and in 2005 had they reached 80% of GDP and 120% in 2008. Fellow scholars have argued that this live capital is responsible in most part for the sustained economic growth in Iceland from 1992-2008.

Despite the positive effects that the quota system has had on the Icelandic economy, it has always remained highly controversial. The debates that have surrounded the system have resulted in uncertainty for those who hold quota titles, therefore, reducing the quality of their title. This reduced quality means that the fisheries have not operated on the social optimal production path. Hence, these debates have only achieved reduction in the prosperity and success of its people. Estimates have shown that from 1984-2014 cod fisheries could have yielded 598 billion ISK more in profits than actually occurred. In 2014 the "sunken billions" were 1% of GDP, in other words, or 12 billion ISK. On average the "sunken billions" have yielded 2.2% of GDP. Estimates have also shown that if the quota system had been implemented in 1975, they would have yielded 311 billion ISK more in discounted profits compared to the optimal production path from 1984.

However, the results indicate that the efficiency of the fisheries have been improving since 1984, plus, the current production path has been converging to the optimal production path. Though this is not happening quickly and current fisheries are still not catching all the possible profits that the seas have to offer. In 2014 current profits yielded 63% that of the optimal solution. Among other things, this can be understood to be a result of the debates, which have prevented the fisheries reaching the optimal path.

The above results strongly indicate how harmful the debates around the Icelandic quota system have been and how they have actually reduced the performance of the marine industry. The debates have mostly been about who should gain from the fisheries and how these gains should be redistributed back to the people. As the results indicate, these debates have only achieved a smaller rather than larger financial share for the people.

To achieve maximum performance from the marine sector, and thus maximum prosperity for the nation, it is important that Iceland's people understand the nature of the fisheries and how they were plagued with the common property problem before the introduction of the quota system. They should learn how the quota system redressed this problem, and understand that the purpose of the quota system is not only to ensure that fishing is carried out on a sustainable basis, but also to achieve maximum wealth. With this information, perhaps people could become aware of the quota system's achievements and how it has reshaped the world they live in. It is important that they realise how harmful the debates have been to and for their welfare. Only when all this information has been understood and assimilated, and therefore the conditions met, will it be possible to harvest the wealth of the seas to their maximum sustainable potential and ensure the prosperity and success of the Icelandic people.

8. References

Acemoglu, D., & Robinson, J. (2008). The role of institutions in growth and development. *World Bank, Washington DC*.

Acemoglu, D., & Robinson, J. (2012). *Why nations fail: The origins of power, prosperity, and poverty*. New York: Crown.

Acemoglu, D., & Robinson, J. A. (2010). Why is Africa poor? *Economic history of developing regions*, *25*(1), 21-50.

Alchian, A. A. (1967). *Pricing and Society.* Occasional papers, no. 17. Westminister: Institute of Economic Affairs.

Alvarleg aðför að tilverurétti okkar. (1985, 23. Nov). *Dagblaðið Vísir.*

Arnason, R. (1990). Minimum information management in fisheries. *Canadian Journal of economics*, 630-653.

Arnason, R. (1995). *The Icelandic fisheries: Evolution and management of a fishing industry*. Oxford: Fishing New Books.

Árnason, R. (2001). *Kvótakerfi í fiskveiðum og tekjudreifing.* 48. Fjármálatíðindi. Reykjavík.

Arnason, R. (2008). Basic Fisheries Economics. In *Unpublished/manuscript*. *A paper prepared for the Workshop on Policy and Planning for Coastal Fisheries Resources. University of South Pacific, Suva, Fiji, January* (Vol. 28).

Arnason, R. (2008). Iceland‘s ITQ system creates new wealth. *The Electronic Journal of Sustainable Development, 1(2),* 35-41.

Árnason, R., & Agnarsson, S. (2005). *Sjávarútvegur sem grunnatvinnuvegur á Íslandi*. 52. Fjármálatíðindi. Reykjavík.

Arnason. R. (1999). *Property Rights as a Means of Economic Organization*. Reykjavík: Author.

Árnason. R. (2004). *Náttúruauðlindir, hagvöxtur og velferð.* 51. Fjármálatíðindi. Reykjavík

Barzel, Y. (1997). *Economic Analysis of Property Rights*. UK: Cambridge University Press.

Bjorndal, T., Gordan, D., Arnason, R., &Sumalia, P. (2007). *Advances in Fisheries Economics*. Oxford: Blackwell Pub.

Coase, R. H. (1960). Problem of social cost, the. Jl & econ., 3, 1.

De Soto, H. 2000. The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else. New York: Basic Books.

Demsetz, H. (1967). Toward a theory of property rights. *The American economic review*, 347-359.

Eggertsson, T. (1990). Economic behaviour and institutions: Principles of Neoinstitutional Economics. Cambridge University Press.

Eggertsson, T. (2011). 2. The unbearable lightness of A–useful knowledge and economic growth. *Law, Economics and Evolutionary Theory*, 54.

Eggertsson. T. (2003). *Open access versus common property*. Property rights: Cooperation, conflict, and law. Princeton University Press, Princeton, NJ.

Furubotn, E. G. (2005). *Institutions and Economic Theory: The Contribution of the New Institutional Economics*. Ann Arbor: University of Michigan Press.

Hagfræðistofnun. (2007). *Þjóðhagsleg áhrif aflareglu.* Skýrsla nr. C07:09. Háskóli Íslands. Reykjavík.

Hagfræðistofnun. (2010). *Skilvirkni markaða fyrir aflaheimildir.* Skýrsla nr. C10:04. Háskóli Íslands. Reykjavík.

Hannesson, R. (2004). *The Privatization of the Oceans*. London: The MIT press.

Hayek, F. A. (1945). The Use of Knowledge in Society. *American Economic Review, 4,* 519 - 530.

Heimisson, Ásgeir F. (2014). *Umfang sjávarútvegs á Austfjörðum*. Report done by Heimisson for Austurbrú.

Íslenski Sjávarklasinn. (2013). *Sjávarklasinn á Íslandi: Efnahagsleg umsvif og afkoma 2013.* Reykjavík. Íslenski Sjávarklasinn.

Johnson, R. N. (1995). Implications of taxing quota value in an individual transferable quota fishery. *Marine Resource Economics, 10,* 327-340.

Kvótinn er hemill á getu og gerðir manna. (1985, 11. Sep). *Morgunblaðið.*

Libecap, G. D. (1986). Property rights in economic history: Implications for research. *Explorations in Economic History*, *23*(3), 227-252.

Líndal, S. and Örlygsson, Þ. (1998). *Um nýtingu fiskistofna og töku gjalds fyrir nýtingu þeirra.* Kafli 2. Skýrsla auðlindanefndar í mars 1999. Reykjavík.

Locke, A. (2013). Property rights and development briefing: property rights and economic growth. *ODI Strategic Policy Impact and Research Unit.*

Lög um stjórn fiskveiða. (2006). *Nr.116 10.*

Mankiw, N. G., Romer, D., & Weil, D. N. (1990). *A contribution to the empirics of economic growth* (No. w3541). National Bureau of Economic Research.

Marel. Annual report 2014. Garðabær.

Nechyba, T. (2011). *Microeconomics an Intuitive approach with Calculus.* Mason, OH: South-Western Cengage Learning.

North, D. C. (1976). *The Rise of the Western World: A New Economic History*. Cambridge: Cambridge University Press.

Portes, R. and F.M. Baldursson. 2007. The Internationalization of Iceland's Financial Sector. Icelandic Chamber of Commerce. Reykjavik.

Romer, D. (2012). *Advanced Macroeconimics*. Boston og London: McGraw-Hill.

Samdrátturinn veldur minnkandi atvinnu- eða atvinnuleysi víða. (1984, 4. March). *Morgunblaðið.*

Solow, R. M. (1956). A contribution to the theory of economic growth. *The quarterly journal of economics*, 65-94.

Við þurfum að fá frí frá kvótakerfinu. (1985, 11. Sep). *Morgunblaðið.*

Appendix A

1. The social problem

To solve the socially efficient extraction path of the fisheries requires solving the following problem:

$$\underset{\{q\}}{\text{Max}}\, V = \int_0^\infty \Pi(q,x)e^{-r\cdot t}dt, \tag{A.1}$$

$$subject\ to: \dot{x} = G(x) - q,$$

$$q, x \geq 0,$$

$$x(0) = x_0$$

Where x represents fish biomass, q harvest and r the discount rate. The current value Hamiltonian function corresponding to this problem may be written:

$$\mathcal{H} = \mu_0 \cdot \Pi(q,x) + \mu \cdot (G(x) - q) \tag{A.2}$$

Where μ_0 and μ are the Lagrange multipliers. Furthermore, μ represents the shadow value of the biomass.

The necessary conditions for solving the following problem are defined according to the Pontryagin Maximum Principle (Pontryagin et al., 1962):

i. μ_0 is a constant, 0 or 1 for all t, μ is a continuous function of time and μ_0 and μ cannot be both 0 i.e. $(\mu_0, \mu) \neq 0$.

ii. $\Pi_q = \mu, \forall t\ provided\ q > 0,$

iii. $\dot{\mu} - r \cdot \mu = -\Pi_x - \mu \cdot G_x, \forall t,$

iv. $\dot{x} = G(x) - q, \forall t,$

v. $\lim_{t\to\infty} e^{-r\cdot t} \cdot \mu \cdot (x^\circ - x^*) \geq 0,$

The last transversality condition x*, represents the resource bundle along the optimal path, and x° of any other attainable path. In steady state $\dot{\mu} = \dot{x} = 0$ holds. Thus given that condition i is satisfied (which is almost always the case) it is possible to calculate optimal harvest and biomass growth programs and there equilibrium (q*, x*). Solving conditions ii and iii yields.

$$0 = -\Pi_x - \Pi_q \cdot (G_x - r)$$

$$\rightarrow r \cdot \Pi_q = \Pi_q \cdot G_x + \Pi_x$$

$$\rightarrow r = G_x + \frac{\Pi_x}{\Pi_q} \tag{A.3}$$

And from iv:

$0 = G(x) - q \rightarrow G(x) = q$ (A.4)

Solving (A.3) and (A.4) together gives q^* and x^*, resulting in the optimal solution that maximizes the present value of the functional V in equation (A.1).

2. Non-exclusivity

Too see what the effects of non-exclusion has on the optimal solution it is better to redefine the equation from problem (A.1). It will be more transparent by doing it like that.

When many individuals (fishing firms) operate in the fisheries they solve the following social problem to find the optimal time path of fishing effort that will maximize the present value of the marine sector.

$$\underset{\forall e(i),x}{\text{Max}} \sum_{i=1}^{I} \int_{o}^{\infty} (\Pi(e(i),x,i)) \cdot e^{-r \cdot t}$$

$$subject\ to: \dot{x} = G(x) - \sum_{i=1}^{I} Y(e(i),x,i)$$

$$e(i) \geq 0$$

$$x \geq 0$$

Where we have many individuals, I $(i = 1, 2, \cdots, I)$ and e is fishing effort and Y is harvest. The profit function is $\Pi(e(i),x,i) = P \cdot Y(e(i),x,i) - C(e(i),i), \forall i$, $Y(e(i),x,i)$ represents the harvest function, $C(e(i),i)$ is the cost function, P is the price, r is the discount rate and i represents each individual. Optimal fisheries in steady state $(\dot{x} = 0)$ is defined with the following problem:

$$\underset{\forall e(i),x}{\text{Max}} \sum_{i=1}^{I} \Pi(e(i),x,i)$$

$$subject\ to: G(x) = \sum_{i=1}^{I} Y(e(i),x,i)$$

$$e(i) \geq 0$$

$$x \geq 0$$

The corresponding Lagrange function is:

$\mathcal{L} = \sum_{i=1}^{I} \Pi(e(i),x) + \lambda \cdot (G(x) - \sum_{i=1}^{I} Y(e(i),x)$ (A2.1)

Where λ is the corresponding shadow value of the resource. Taking the differential of (A2.1) yields:

$\frac{\delta \mathcal{L}}{\delta e(i)} = P \cdot Y_{e(i)} - C_{e(i)} - \lambda \cdot Y_{e(i)} = 0\ if\ e(i) > 0, \forall i$ (A2.2)

$\frac{\delta \mathcal{L}}{\delta x} = \sum_{i=1}^{I} P \cdot Y_x + \lambda \cdot (G_x - \sum_{i=1}^{I} Y_x) = 0$ (A2.3)

$$\frac{\delta\mathcal{L}}{\delta\lambda}: G(x) = \sum_{i=1}^{I} Y(e(i), x, i) \tag{A2.4}$$

Equation (A2.2) is the behavioral equation for all the fishing firms and from (A2.3) is it possible to find the shadow value which measures the marginal profit from the fisheries, i.e.:

$$from\ (A2.3) \rightarrow \lambda = \frac{\sum_{i=1}^{I} P \cdot Y_x}{\sum_{i=1}^{I} Y_x - G_x}$$

However, if each individual or firm maximizes only his or her profits, the maximizing problem transforms to:

$$\max_{e(i),x} \Pi(e(i), x, i)$$

$$subject\ to: G(x) = \sum_{i=1}^{I} Y(e(i), x, i)$$

$$e(i) \geq 0$$

$$x \geq 0$$

And the corresponding Lagrange function will be:

$$\mathcal{L} = \Pi(e(i), x, i) + \sigma(i) \cdot (G(x) - \sum_{i=1}^{I} Y(e(i), x) \tag{A2.5}$$

Where $\sigma(i)$ is the corresponding shadow value for each individual of the resource. Differentiating this as before, yields:

$$\frac{\delta\mathcal{L}}{\delta e(i)} = P \cdot Y_{e(i)} - C_{e(i)} - \sigma(i) \cdot Y_{e(i)} = 0 \tag{A2.6}$$

$$\frac{\delta\mathcal{L}}{\delta x} = P \cdot Y_x + \sigma(i) \cdot (G_x - \sum_{i=1}^{I} Y_x) \tag{A2.7}$$

$$\frac{\delta\mathcal{L}}{\delta\sigma(i)}: G(x) = \sum_{i=1}^{I} Y(e(i), x, i) \tag{A2.8}$$

Equation (A2.6) is the behavioural equation for each individual or firm and as before it is possible to find the shadow value for each individual for the fisheries from (A2.7):

$$from\ (A2.7) \rightarrow \sigma(i) = \frac{P \cdot Y_x}{\sum_{i=1}^{I} Y_x - G_x}$$

Behavioural equations (A2.3) and (A2.6) are the same except for their shadow values $(\lambda, \sigma(i))$, to see the difference in them it is best to divide them with each other i.e.

$$\frac{\sigma(i)}{\lambda} = \frac{P \cdot Y_x}{\sum_{i=1}^{I} Y_x - G_x} \cdot \frac{\sum_{i=1}^{I} Y_x - G_x}{\sum_{i=1}^{I} P \cdot Y_x} = \frac{P \cdot Y_x}{\sum_{i=1}^{I} P \cdot Y_x} = \frac{P \cdot Y_x}{IP \cdot Y_x} = \frac{1}{I}$$

$$=> \sigma(i) = \frac{\lambda}{I} \tag{A2.9}$$

We can than see that when there operates only one individual or firm that the shadow values will equal $\sigma(i) = \lambda$, i.e. the shadow value of the individual will equal the true shadow value of the resource. From (A2.9) it is also noted that when there is more than one individual operating in the fisheries, the shadow value will drop, i.e. the marginal value of the fisheries. Let's consider what a higher value on $\sigma(i)$ has on fishing effort. To see this we total differentiate equation (A2.6):

$$\left(\Pi_{e(i)e(i)} - \sigma(i) \cdot Y_{e(i)e(i)}\right) de(i) = Y_{e(i)} d\sigma(i)$$

$$\rightarrow \frac{de(i)}{d\sigma(i)} = \frac{Y_{e(i)}}{\Pi_{e(i)e(i)} - \sigma(i) \cdot Y_{e(i)e(i)}} < 0$$

From this it is noted that when $\sigma(i)$ gets higher, fishing effort decreases. It is then obvious that when more individuals or firms start to operate in the industry (exclusivity decreases) that $\sigma(i)$ decreases and fishing effort will increase.

Appendix B

To solve the social optimal harvesting time path for the Icelandic cod fisheries, which will maximizes the present value of the fisheries requires solving the following:

$$\underset{\{q\}}{\text{Max}}\, V = \int_0^{\infty} (P(q_t) \cdot q_t - C(q_t, x_t)) \cdot e^{-rt}\, dt, \qquad \text{(B.1)}$$

$$subject\ to: \dot{x} = G(x_t) - q_t,$$

Where x is the fish biomass, q is the catch and r is the discount rate (the discount rate is 5%). Statistical study on the above functions led to that they could be explained by the following equations (Agnarsson et al, 2007):

$$C(q_t, x_t) = k \cdot \frac{q_t^{\delta}}{x_t^{\varepsilon}} + fc, \qquad \text{(B.2)}$$

$$G(x_t) = \alpha \cdot x_t - \beta \cdot x_t^2 \qquad \text{(B.3)}$$

$$P(q_t) = p \qquad \text{(B.4)}$$

In other words, with the above information it was not possible to reject the hypothesis that the natural growth function was the “Verhulst” logistic function and that the price of cod is independent of landed volume. Statistical evaluation of the unknown coefficients led to their numerical values. They are shown in table 5.

Table 5. Evaluation of the model coefficients.

Coefficient	**Numerical value**
$\boldsymbol{\alpha}$	0,669853
$\boldsymbol{\beta}$	0,0003353
$\boldsymbol{k}$	57.604,95
$\boldsymbol{\delta}$	1,1
$\boldsymbol{\varepsilon}$	1,0
$\boldsymbol{fc}$	10.000
$\boldsymbol{p}$	220

Source: *Hagfræðistofnun (2007) and Agnarsson et al. (2007).*

Optimal control theory is employed to solve the optimal time path for harvesting in the Icelandic cod fisheries. The corresponding Hamiltonian for (B.1) is:

$$\mathcal{H} = \mu_0 \cdot (p \cdot q) - C(q, x) + \mu \cdot (G(x) - q)$$

Where μ_0 and μ are the Lagrange multipliers. Furthermore, μ represents the shadow value of the biomass.

The necessary conditions for solving the following problem are defined according to the Pontryagin Maximum Principle (Pontryagin et al., 1962):

i. μ_0 is a constant, 0 or 1 for all *t*, μ is a continuous function of time and μ_0 and μ cannot be both 0 i.e. $(\mu_0, \mu) \neq 0$.

ii. $\mathcal{H}_q = p - C_q - \mu = 0 \quad \rightarrow \mu = p - C_q$

iii. $\dot{\mu} - r \cdot \mu = -\mathcal{H}_x = C_x - \mu \cdot G_x \rightarrow \dot{\mu} = C_x - \mu \cdot (G_x - r)$

iv. $\dot{x} = G(x) - q$

Other conditions are not necessary to find the optimal time path. Thus, given that condition i. is satisfied (which is almost always the case) it is possible to calculate optimal harvest and biomass growth programs. In steady state it is assumed that $\dot{x} = \dot{\mu} = 0$ holds. Thus, solving conditions ii. and iii. together leads to the following:

$$\rightarrow C_x - \left(p - C_q\right) \cdot (G_x - r) = 0$$

$$\rightarrow C_x = \left(p - C_q\right) \cdot (G_x - r)$$

$$\rightarrow \frac{C_x}{p - C_q} = G_x - r$$

$$\rightarrow r = G_x - \frac{C_x}{p - C_q}$$

Insertion into this solution yields:

$$r = \alpha - 2 \cdot \beta \cdot x - \frac{(-\frac{k \cdot q^{\delta}}{x^2})}{p - (k \cdot \delta \cdot \frac{q^{\delta - 1}}{x})} \tag{B.5}$$

From iv. we have:

$$q = \alpha \cdot x - \beta \cdot x^2 \tag{B.6}$$

From equations (B.5) and (B.6), with some algebra it is possible to find the optimal numerical values for *q* and *x*. Solving this with algebra and with a discount rate of 5%, yields:

$$q^* = 321{,}3679$$

$$x^* = 1197{,}19$$

Employing these solutions it is possible to calculate the optimal catch rule (feedback rule) for different periods, i.e. after when the optimal rule is employed it will vary.

The optimal catch rule from 1984 is:

$$q_t = \begin{cases} -402{,}498 + 0{,}0005 \cdot x_t^2, if\ x_t \geq 892{,}722\ thousand\ tons. \\ 0 \qquad\qquad\qquad\qquad\quad , if\ x_t < 892{,}722\ thousand\ tons. \end{cases}$$

Appendix C

Table 6. Data for fisheries.

Year	GFI volume index	Capital volume index	Labour	Fish stock*	Weight capital	Weight labour
1980	76,7	65,4	5.545	69.279.664.797	0,200	0,800
1981	79,5	67,9	5.587	73.309.794.904	0,151	0,849
1982	70,3	69,7	5.745	67.415.110.153	0,068	0,932
1983	55,5	70,3	5.810	58.020.426.230	0,147	0,853
1984	55,1	70,6	5.576	57.469.800.087	0,221	0,779
1985	64,8	71,8	6.085	61.115.319.584	0,249	0,751
1986	79,9	79,2	6.257	65.537.254.312	0,282	0,718
1987	93,7	88,0	6.838	70.231.569.028	0,255	0,745
1988	100,2	98,3	6.613	72.229.155.922	0,290	0,710
1989	96,1	100,2	6.777	71.896.616.512	0,285	0,715
1990	100	101,2	7.087	67.036.117.650	0,310	0,690
1991	112,4	100,2	6.200	61.004.913.631	0,322	0,678
1992	113,5	104,7	6.700	57.018.454.285	0,319	0,681
1993	120,5	102,2	6.600	57.773.131.473	0,327	0,673
1994	112,9	101,6	6.400	54.009.898.870	0,310	0,690
1995	112,6	97,9	7.000	51.078.610.364	0,345	0,655
1996	116,2	100,0	7.100	51.309.883.275	0,320	0,680
1997	114,6	98,3	6.300	49.465.025.685	0,365	0,635
1998	107,1	101,3	6.200	48.727.403.940	0,385	0,615
1999	103	97,3	7.200	50.694.809.244	0,355	0,645
2000	100	100,0	6.100	49.995.591.500	0,367	0,633
2001	100,5	103,2	6.000	47.917.433.699	0,485	0,515
2002	102,6	103,9	5.300	49.699.150.130	0,385	0,615
2003	98,2	100,8	5.100	49.418.341.083	0,373	0,627
2004	102,4	101,4	4.600	51.673.590.334	0,314	0,686
2005	100	98,5	5.100	51.538.210.188	0,309	0,691
2006	95,1	97,1	4.600	49.009.458.687	0,359	0,641
2007	92,3	95,9	4.500	48.041.055.942	0,322	0,678
2008	91,1	91,9	4.200	46.887.065.310	0,372	0,628
2009	96	89,7	4.700	47.615.492.824	0,414	0,586
2010	86,3	87,0	5.300	43.351.399.560	0,407	0,593
2011	89	87,6	5.200	43.117.855.004	0,374	0,626
2012	92,4	87,3	4.900	45.570.644.829	0,361	0,639
2013	95,6	83,5	3.600	49.355.790.533	0,344	0,656

Source: *Statistics Iceland and author's calculations.*

**Aggregate measure of fish stocks in ISK.*

*Table 7. **Data for industries in total.***

Year	GFI volume index	Capital volume index	Labour	Weight capital	Weight labour
1980	59,13	73,97	105.596	0,342	0,658
1981	61,66	77,52	111.103	0,341	0,659
1982	62,98	80,56	113.929	0,336	0,664
1983	61,62	82,29	114.977	0,407	0,593
1984	64,17	84,72	116.566	0,423	0,577
1985	66,29	87,36	120.807	0,380	0,620
1986	70,44	90,10	124.605	0,380	0,620
1987	76,46	94,36	131.836	0,330	0,670
1988	76,39	97,81	127.945	0,319	0,681
1989	76,59	99,43	126.090	0,356	0,644
1990	77,49	101,46	124.763	0,422	0,578
1991	77,30	98,67	136.900	0,375	0,625
1992	74,70	95,74	136.800	0,383	0,617
1993	75,68	92,15	136.600	0,395	0,605
1994	78,41	88,83	137.700	0,408	0,592
1995	78,51	86,44	141.900	0,391	0,609
1996	82,26	86,70	142.100	0,378	0,622
1997	86,11	81,25	142.000	0,429	0,571
1998	91,66	88,56	148.000	0,407	0,593
1999	95,47	93,75	153.400	0,373	0,627
2000	100,00	100,00	156.500	0,364	0,636
2001	103,76	103,99	159.100	0,392	0,608
2002	104,23	106,38	156.700	0,384	0,616
2003	107,06	110,11	157.100	0,365	0,635
2004	115,87	118,09	156.500	0,366	0,634
2005	122,82	132,98	161.600	0,342	0,658
2006	128,02	152,66	169.800	0,313	0,687
2007	140,47	164,36	177.500	0,329	0,671
2008	142,08	169,28	179.100	0,383	0,617
2009	134,77	164,49	168.000	0,462	0,538
2010	130,63	160,64	167.400	0,452	0,548
2011	133,76	159,31	167.400	0,432	0,568
2012	135,52	158,38	169.100	0,415	0,585
2013	140,35	156,38	174.900	0,410	0,590

Source: *Statistics Iceland and author's calculations.*

Appendix D

Table 8. Sunken billions.

Sunken billions				
Year	**Optimal**	**Actual**	**Difference**	**Difference as % of GDP**
1984	-7.375	30.410	-37.785	-7,1%
1985	38.431	25.330	13.101	2,4%
1986	31.275	25.886	5.390	0,9%
1987	33.792	36.153	-2.360	-0,4%
1988	32.941	34.890	-1.949	-0,3%
1989	33.233	32.196	1.037	0,2%
1990	33.133	22.659	10.474	1,6%
1991	33.167	12.677	20.490	3,2%
1992	33.156	-104	33.259	5,3%
1993	33.160	2.994	30.166	4,8%
1994	33.158	-728	33.887	5,2%
1995	33.159	-2.013	35.172	5,4%
1996	33.159	3.687	29.471	4,3%
1997	33.159	9.254	23.905	3,2%
1998	33.159	9.900	23.258	2,9%
1999	33.159	11.472	21.687	2,6%
2000	33.159	2.092	31.067	3,6%
2001	33.159	7.673	25.486	2,9%
2002	33.159	7.731	25.427	2,8%
2003	33.159	8.148	25.011	2,7%
2004	33.159	11.821	21.338	2,1%
2005	33.159	7.891	25.268	2,4%
2006	33.159	5.816	27.343	2,5%
2007	33.159	3.367	29.792	2,5%
2008	33.159	2.456	30.703	2,5%
2009	33.159	7.874	25.285	2,2%
2010	33.159	7.891	25.268	2,2%
2011	33.159	9.839	23.319	2,0%
2012	33.159	14.722	18.437	1,6%
2013	33.159	20.186	12.973	1,1%
2014	33.159	21.156	12.003	1,0%
Sum	*991.246*	*393.325*	*597.920*	
Average	*31.976*	*12.688*	*19.288*	*2,2%*

Source: *Author's calculations.*

Table 9. Optimal fisheries from 1995.

Time	Year	Biomass	q	x_(x+1)	Revenue	Costs	Profits	Discounted profits
0	1995	557	70	756	15.327	21.014	-5.687	- 5.687
1	1996	756	128	943	28.267	25.902	2.365	2.253
2	1997	943	200	1.077	43.910	30.712	13.199	11.972
3	1998	1.077	260	1.149	57.270	34.290	22.980	19.851
4	1999	1.149	296	1.179	65.209	36.258	28.951	23.818
5	2000	1.179	312	1.191	68.730	37.099	31.630	24.783
6	2001	1.191	318	1.195	70.042	37.409	32.633	24.352
7	2002	1.195	320	1.196	70.495	37.515	32.980	23.438
8	2003	1.196	321	1.196	70.647	37.551	33.096	22.401
9	2004	1.196	321	1.196	70.697	37.562	33.135	21.359
10	2005	1.196	321	1.196	70.714	37.566	33.148	20.350
11	2006	1.196	321	1.196	70.720	37.568	33.152	19.383
12	2007	1.196	321	1.196	70.721	37.568	33.153	18.461
13	2008	1.196	321	1.196	70.722	37.568	33.154	17.582
14	2009	1.196	321	1.196	70.722	37.568	33.154	16.745
15	2010	1.196	321	1.196	70.722	37.568	33.154	15.948
16	2011	1.196	321	1.196	70.722	37.568	33.154	15.188
17	2012	1.196	321	1.196	70.722	37.568	33.154	14.465
18	2013	1.196	321	1.196	70.722	37.568	33.154	13.776
19	2014	1.196	321	1.196	70.722	37.568	33.154	13.120
							Sum:	333.558
							Discounted for eternity:	262.403
							Sum:	**595.961**

Source: *Marine Research Institute and author's calculations.*

*Table 10. **Optimal fisheries from 2000.***

Time	Year	Biomass	q	x_(x+1)	Revenue	Costs	Profits	Discounted profits
0	2000	590	80	788	17.692	22.176	-4.484	-4.484
1	2001	788	143	964	31.565	27.233	4.332	4.126
2	2002	964	215	1.084	47.256	31.953	15.302	13.879
3	2003	1.084	271	1.144	59.678	35.253	24.425	21.099
4	2004	1.144	303	1.169	66.573	36.966	29.607	24.358
5	2005	1.169	316	1.178	69.494	37.669	31.825	24.935
6	2006	1.178	321	1.181	70.560	37.923	32.636	24.354
7	2007	1.181	322	1.182	70.924	38.010	32.914	23.392
8	2008	1.182	323	1.183	71.046	38.039	33.007	22.341
9	2009	1.183	323	1.183	71.086	38.048	33.038	21.297
10	2010	1.183	323	1.183	71.100	38.051	33.048	20.289
11	2011	1.183	323	1.183	71.104	38.052	33.052	19.325
12	2012	1.183	323	1.183	71.106	38.053	33.053	18.405
13	2013	1.183	323	1.183	71.106	38.053	33.053	17.529
14	2014	1.183	323	1.183	71.106	38.053	33.053	16.694
							Sum:	267.538
							Discounted for eternity:	334.858
							Sum:	**602.396**

Source: *Marine Research Institute and author's calculations.*

*Table 11. **Optimal fisheries from 2005.***

Time	Year	Biomass	q	x_(x+1)	Revenue	Costs	Profits	Discounted profits
0	2005	724	131	902	28.807	26.963	1.844	1.844
1	2006	902	203	1.030	44.740	32.091	12.649	12.047
2	2007	1.030	265	1.099	58.341	35.905	22.436	20.350
3	2008	1.099	302	1.129	66.421	38.002	28.419	24.550
4	2009	1.129	318	1.139	70.003	38.898	31.105	25.590
5	2010	1.139	324	1.143	71.338	39.228	32.110	25.159
6	2011	1.143	326	1.144	71.799	39.341	32.458	24.221
7	2012	1.144	327	1.145	71.954	39.379	32.575	23.150
8	2013	1.145	327	1.145	72.005	39.392	32.613	22.074
9	2014	1.145	327	1.145	72.022	39.396	32.626	21.031
							Sum:	200.016
							Discounted for eternity:	405.653
							Sum:	605.669

Source: *Marine Research Institute and author's calculations.*

Table 12. Actual cod fisheries.

Time	Year	Biomass	q	Revenue	Costs	Profits	Discounted profits*
0	1980	1.490	432	95.040	40.641	54.399	54.399
1	1981	1.242	465	102.300	49.860	52.440	49.943
2	1982	971	380	83.600	50.832	32.768	29.721
3	1983	791	298	65.560	48.364	17.196	14.855
4	1984	914	382	84.040	53.630	30.410	25.019
5	1985	928	323	71.060	45.730	25.330	19.847
6	1986	854	365	80.300	54.414	25.886	19.316
7	1987	1.029	390	85.800	49.647	36.153	25.693
8	1988	1.030	378	83.160	48.270	34.890	23.615
9	1989	1.001	363	79.860	47.664	32.196	20.754
10	1990	841	335	73.700	51.041	22.659	13.911
11	1991	698	308	67.760	55.083	12.677	7.412
12	1992	551	265	58.300	58.404	- 104	- 58
13	1993	595	251	55.220	52.226	2.994	1.588
14	1994	576	178	39.160	39.888	-728	-368
15	1995	557	169	37.180	39.193	-2.013	-968
16	1996	671	181	39.820	36.133	3.687	1.689
17	1997	783	203	44.660	35.406	9.254	4.037
18	1998	721	244	53.680	43.780	9.900	4.114
19	1999	731	260	57.200	45.728	11.472	4.540
20	2000	590	235	51.700	49.608	2.092	788
21	2001	688	234	51.480	43.807	7.673	2.754
22	2002	729	208	45.760	38.029	7.731	2.643
23	2003	740	208	45.760	37.612	8.148	2.653
24	2004	800	227	49.940	38.119	11.821	3.665
25	2005	724	213	46.860	38.969	7.891	2.330
26	2006	701	196	43.120	37.304	5.816	1.636
27	2007	681	170	37.400	34.033	3.367	902
28	2008	704	146	32.120	29.664	2.456	626
29	2009	799	181	39.820	31.946	7.874	1.913
30	2010	843	169	37.180	29.289	7.891	1.826
31	2011	932	170	37.400	27.561	9.839	2.168
32	2012	1.047	195	42.900	28.178	14.722	3.090
33	2013	1.161	224	49.280	29.094	20.186	4.035
34	2014	1.106	240	52.763	31.608	21.156	4.027

Source: *Marine Research Institute and author's calculations.*

**to calculate discounted profits for all eternity, the fisheries are expected to follow the current catch rule of the Marine Research Institute which is 20% of the fish biomass (when they reach equilibrium, discounted profits are calculated).*