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Resource rent in aquaculture

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Abstract

Resource rent in aquaculture (RRA) is any payment to a farm and site owner, on land or sea, in excess of the costs needed to bring that farm into production. For analytic and policy purposes it may be useful to distinguish among different types of RRA. Three types will be discussed: rent associated with the classical economists Ricardo (1821) and Faustmann (1849), as well as oligopoly rent from access regulation (licensing) and hampered output. The latter can arise in the case of downward sloping demand for a particular type of seafood from an aquaculture country. The similarities and differences among these types of rent are discussed and the distinctions between business economics indicators and RRA are clarified. The theory is applied to the case of Atlantic salmon in Norway and white leg shrimp in Vietnam. Based on cost and revenue data for 2016 from 84 firms from the Directorate of Fisheries in Norway; and for 2014 from 318 farms and for 2016 for 120 farms from two surveys in Vietnam, both business economics and RRA indicators are calculated, after revealing the cost structure of the farms. In theory, the RRA rate may be higher or lower than the profit rate, depending on the capital structure and intensity of the firms. The analysis demonstrates very high profit and rent margins in the Norwegian salmon industry, and lower, but positive ones in Vietnam. However, the profit and rent rates are much higher in Vietnam due to the low capital intensity of the shrimp industry.

Keywords: Resource rent in aquaculture, Faustmann rent, Ricardo rent, market rent.

1. INTRODUCTION

The concept of resource rent is well known from the economic literature on oil, gas, and other minerals, as well as on agriculture, forestry and fisheries (Ricardo, 1821; Faustmann, 1849; Gordon, 1954). For seafood production, aquaculture in 2014 surpassed that of capture fisheries and is still expanding, whereas capture has come to a standstill (FAO, 2016; Nadarajah and Flaaten, 2017). Despite the increased importance of the former, resource rent issues are rarely discussed in connection with aquaculture. A pertinent question is – can resource rent be realized in aquaculture? Further, what kind of rent would this be, compared to what is found in other natural resource-based industries? Resource rent in fisheries is a natural point of departure for discussing resource rent in aquaculture (RRA) (Flaaten, Heen and Matthíasson, 2017).

RRA is any payment to a farm and site owner, on land or sea, in excess of the costs needed to bring that farm into production, and different types of RRA may exist. Aqua-land is an inelastic factor of production, at least for good quality locations. In principle, sites could be ranked from the very best one suited for aquaculture farming to the marginal one where hardly anyone would be interested in establishing a farm, due to for example, bad water quality, sea and wave exposure, weather and climatic conditions, low biotechnical productivity, or costly distance to the input and output markets. The surplus that arises in agriculture due to the difference between the marginal and intra-marginal location is the differential rent, or "that portion of the produce of the earth which is paid to the landlord for the use of the original and indestructible powers of the soil", which is called Ricardo rent (Ricardo, 1821). In a way, the intra-marginal rent (IMR) in fisheries (Copes, 1972), corresponds to that in agriculture, where it usually arises from differences in the natural capital and beneficial distance to the input and output markets. In fisheries, however, IMR is mainly due to differences in the manmade capital, such as vessels and fishing gear, and the operational skills of skippers and crew (Duy et al., 2012). In aquaculture, differences in site-specific nature characteristics may cause profitability differences among farms, and this can be classified as resource rent. Of course, operational means and skills of farms can differ, but this is not differential rent in the Ricardo-sense.

Governments can authorize firms to establish aquaculture farms, and such institutional arrangements usually limit the number of farms compared to open access and competitive markets. When the aquaculture industry faces a downward sloping demand for its products, limitation on the number of licences may limit the output of fish, thereby increasing the price compared with that of perfect competition. This is the case whether the official arguments for a licensing system are for environmental protection or market reasons. Thus, some returns are associated with legally enforced monopolies, oligopolies, or cartels through licensing; let us simply call this market rent, and together with the Ricardo rent it constitutes resource rent in aquaculture (RRA). In analysing the accounts of a firm, it can be difficult to disentangle market rent from Ricardo rent, but to do this is one of the objectives of what follows. The concepts of Faustmann rent, Ricardo rent, and market rent will be discussed theoretically, followed by accounting-based examples from shrimp (White leg shrimp, WLS, *Litopenaeus vannamei*) in Vietnam and Atlantic salmon (*Salmo salar*) in Norway.

2. THEORY OF RENT[1]

2.1 The basic problem

A fish farm with a given capacity, be it earthen ponds or floating cages in the sea, releases recruits into the cage, to use this terminology throughout, and feed the fish that grow. A key question is – when to harvest with the objective of maximizing the owner's wealth? To simplify initially, the costs of recruits, feed, and slaughter are disregarded, and the emphasis is on discounting and wealth maximization. Let $V(t)$ be the value of fish at time t and δ the interest rate, or opportunity cost of capital. The problem is to $MAX_t\ \Pi(t) = V(t)e^{-\delta t}$, using continuous time. We derive the first order condition (FOC) for the maximum, also called the simple Fisher condition:

(1) $$\frac{V'(t)}{V(t)} = \delta.$$

The Fisher harvest time t^* can implicitly be found from (1); though, for management this has for long been consider of very little importance (Samuelson, 1976). The relative value growth, on the left-hand side of (1), is, by assumption, declining, and this corresponds well to actual cases of biological growth (for a constant price per kg of fish).

2.2 Faustmann – Rotation issues

We have discussed optimality conditions for the release and harvest of one cohort, leading to equation (1). However, as soon as one cohort is harvested, it gives room for the next one to be released into the cage, immediately or after a while if the facilities need a fallow period for cleaning or repair. Since fish grow relatively slower with age, harvest of older fish may give room for younger and faster-growing fish, and this should be considered simultaneously with the economic issues discussed above. A sequence of rotations should be studied to find the

[1] Some sentences and paragraphs are quotations from Flaaten, 2018.

best utilization of the total capital, including physical capital, fish capital, and site capital. The site has a value in itself, since good locations for aquaculture are in limited supply, both for earthen ponds and floating sea cages. Assuming that the parameters are constant across time, all the rotation periods will be of the same length, and each optimal rotation period proves to be shorter than the Fisher period (Guttormsen, 2008). The issue of seasonal growth and harvesting may be important for actual farm operation, but is excluded from this analysis (Jobling, 2003; Thyholdt, 2014). Following the previous notation, *V(t)* is the value of fish at time *t* (age), disregarding the explicit costs of recruitment, feed, and slaughter. Instead of the Fisher rule (1), we now have the rotation rule, or Faustmann rule, as follows (see Annex):

(2) $$V'(t) = \delta V(t) + \frac{\delta V(t) e^{-\delta t}}{1 - e^{-\delta t}} = \delta V(t) + \delta \frac{V(t)}{e^{\delta t} - 1},$$

where $V'(t)$ is the marginal change in fish biomass value and $\delta V(t)$ is the opportunity cost of the fish biomass capital. The Faustmann rule from (2) is introduced by Martin Faustmann (1822-1876) and formulated in a forestry context where trees grow in a similar way as fish, but at a much slower pace. Implicitly we can find the optimal rotation length *t*** from equation (2). The second part of the second term on the rhs of (2), $\frac{V(t)}{e^{\delta t}-1}$, is the site value, or the natural resource capital of the aquaculture farm. The site value multiplied by the interest rate δ, gives the opportunity cost of the fish farm itself. This warrants some further comments. Recall that the present value of an eternal stream of *A* dollars annually at the instantaneous interest rate of δ is $\frac{A}{\delta}$, with δ as a fraction. The value of a one-dollar investment today at time *t* is $e^{\delta t}$, and $(e^{\delta t} - 1)$, the denominator of the last term on the rhs of (2), is the added value at time t of a one-dollar investment today. The net harvest value in aquaculture, *V(t)*, emanates at the end of each rotation period, and not (usually not) annually as *A* in this example. The actual rotation period may be more than a year (salmon) or shorter (tropical shrimp).

An alternative way of formulating the Faustmann equation is on the relative form:

(3) $$\frac{V'(t)}{V(t)} = \frac{\delta}{1 - e^{-\delta t}}.$$

From the discussion and assumptions above, we know that the lhs of (3) declines with *t*, and since the denominator on the rhs is less than unity the value of the rhs is greater than δ. Thus, the Faustmann rule leads to an optimal age of harvest *t***<*t**. Figure 1 illustrates this, using $V(t)e^{-\delta t} = p(w)w(t)Re^{-Mt}e^{-\delta t}$ in the Faustmann equation (3), with *p(w)* = size dependent price of fish, *w(t)* = weight of fish, *R* = number of recruits, *M* = natural mortality, and parameters in the Annex. Using this we find for constant *p*, *p'(w)=0*,

(4) $$\frac{w'(t)}{w(t)} = \frac{\delta}{1-e^{-\delta t}} + M.$$

The lhs of equation (4) graphically is the downward sloping relative growth curve of fish in Figure 1. The rhs of equation (4) is also downward sloping, asymptotically towards $\delta+M$. This implies that the optimal rotation period is shorter when many rotations are included, t^{**}, in the analysis instead of just a single cycle, t^{*}. Age dependent costs, such as feed, will affect the optimal rotation period (further reduction from t^{**}) and so will seed costs in the many rotations case; for a discussion of the cases of costs of recruits, feed and slaughter, see Flaaten, 2018.

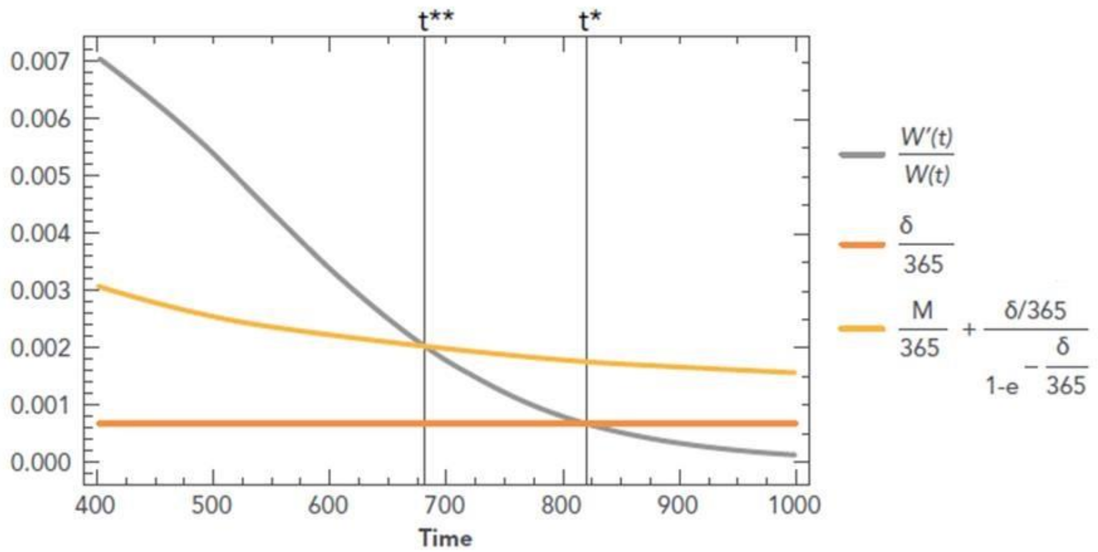

Figure 1. The Fisher single rotation optimal age of harvest is t^{*}, whereas the Faustmann optimal multiple rotations age of harvest is t^{**}.

Source: See Annex – Fish growth.

As noted above, the main three types of capital in aquaculture are physical capital, fish capital, and site capital. Disregarding the physical capital, to simplify, the distinction between fish and site capital is demonstrated by the Faustmann rule in (2). If, underlining *if*, the optimal rotation period had been one year, the value of the aquaculture farm would have been $\frac{V(t=1)}{\delta}$, whereas $\frac{V(t)}{e^{\delta t}-1}$ is the site value of the farm in the general case. Note that the rotation time *t* in (2) - (3) is endogenous, to be derived from this analysis; for fast growing tropical species, such as shrimp, the rotation period is usually well below one year, whereas for temperate fish, such as salmon, the rotation time traditionally has been two–three years. Faustmann rent will vary with environmental, biological, economic, and other characteristics of importance for the establishment and operation of an aquaculture farm. Price of fish is a very important element of the numerator of the site value, and this will vary with type of market, be it competitive or oligopoly. The same applies to the operating costs that often vary among farms. Thus, the concept of Faustmann rent is related to a single farm at a given location. However, in the empirical analysis below, Faustmann site value and rent often have to be calculated for a multi-farm firm as the average across locations or farms. This is, in particular, the case for salmon firms, whereas the investigated shrimp farms mainly are "one firm/family–one farm".

2.3 Ricardo rent

The basic fisheries economic model (Gordon, 1954) demonstrates that in equilibrium, the potential resource rent is wasted under open access if the fleet consists of homogenous vessels. However, it is also known that producers' surplus, called IMR in fisheries, may exist even under open-access equilibrium (Copes, 1972). In aquaculture, differences in site-specific nature characteristics may also cause profitability differences among farms. This resembles the issues discussed by Ricardo for agriculture and warrants further discussion. A Heckser-Salter diagram may help explaining this. For an aquaculture industry with n firms, this is done by ranking the firms according to increasing production cost per kg production, with the lowest cost firm to the left, as in Figure 2. Thus, firm one, to the left, is the most cost-efficient and firm *n* the least cost-efficient.

Cost influences the outcome value of aquaculture firms, illustrated by the function *V(t).* For heterogeneous firms rent may differ due to natural characteristics or managerial skills and real capital. The former resembles what is called Ricardo rent; the difference between the produce obtained by the employment of two equal quantities of capital and labor. To distinguish between rent caused by differences in natural characteristics and managerial skills/capital in empirical analysis requires micro data, including locational data. In the empirical sections of this paper, such data is not available and therefore the theoretical discussion is kept simple, without including heterogeneity into the *V(t)* function.

If the firms produce a homogenous product for a competitive market, the law of one price exists. Moreover, profit per kg of product decreases from the left to the right. On the other hand, if e.g. transport costs, product quality, or the degree of processing differ, the farm gate price will also differ, to change the profit ranking of firms. Therefore, perfect (negative) correlation between cost and profit should not necessarily be expected empirically.

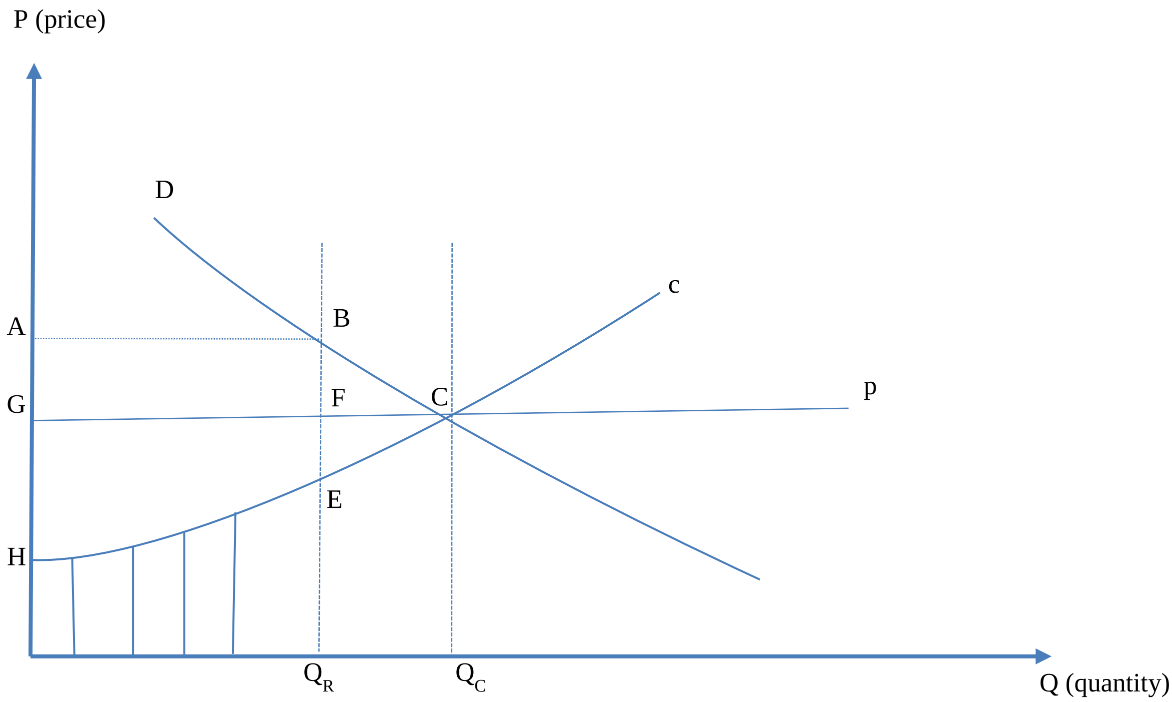

Figure 2. Ricardo rent in the regulated market (Q_R) is HEFG; and in the non-regulated market (Q_C) is HECG; Market rent in the regulated market (Q_R) is ABFG

2.4 Market rent

In Figure 2, with the upward sloping marginal cost curve c, the competitive equilibrium is at point C with total production equal to Q_C for the downward sloping demand D. The Ricardo rent in this case is the area GCEH. If the industry is regulated to remove or to avoid entering of the least cost-efficient firms, total production is reduced to Q_R in Figure 2, implying a loss in the Ricardo rent equivalent to the area FCE. However, there is a market rent gain of ABFG, and if this exceeds CFE there will be a net gain for the industry, disregarding consumer surplus and regulation cost. As Figure 2 indicates, it is possible that the total industry gains from an output constrained regulation if demand is inelastic; that is, if the industry has some market power (Norwegian salmon to be discussed below). On the other hand, if the industry is a price taker in the world market, with horizontal demand, output regulations will cause a loss of Ricardo rent (shrimp in Vietnam to be discussed). For aquaculture industries, resource rent is the sum of Ricardo rent and market rent. The industry depends on the natural resources of water and land/space, just as with other resource industries such as fisheries, forestry, agriculture, hydroelectric power, minerals, and oil and gas.

If industry regulation affects production of each firm, for example by licences or feed quotas, and not just the least cost-efficient ones as discussed above, the width of every bar in Figure 2 may be affected. Relaxation or constraining of regulations will probably affect both the width and the heights of the bars in Figure 2. When regulation effectively constrains production and increases unit costs of a firm, there will, in principle, be an opportunity cost inflicted upon the firm. We could ask – what is the firm's willingness to pay for getting rid of regulations and to expand production, fully or partly? However, it could be that even though a single firm would prefer to avoid regulations affecting itself, the laissez-faire policy with no industry regulations would be even worse due to competition. This is a parallel to the issue of cheating in a cartel or in a cooperative game. Problems like this exist in many aquaculture industries, including for salmon in Norway.

The relationship between Faustmann rent on the one hand and the Ricardo and market rent on the other, warrants some comments. The site value was derived above and the Faustmann rent as $\delta \frac{V(t)}{e^{\delta t}-1}$. From the discussion in relation to Figure 2, *V(t)* can be seen as the combined market and Ricardo rent for each farm, implying that the Faustmann rent varies between farms the same way as the Ricardo rent per farm varies. Farms to the left in Figure 2 have a higher Faustmann rent and site value than less cost-efficient farms to the right. In addition, site value and Faustmann rent also depend on whether the industry is output regulated or not, and on the industry market power. The highest site value is expected for cost-efficient farms in an output regulated industry with market power, whereas (almost) homogenous aquaculture farms exporting as price takers to a competitive world market should not be expected to have site values above the opportunity cost of capital in the area. These issues shall be further discussed below in relation to the shrimp and salmon industries of Vietnam and Norway, respectively.

3. SHRIMP AQUACULTURE IN VIETNAM AND SALMON AQUACULTURE IN NORWAY

Norway and Vietnam are among the largest aquaculture producers in the world. In 2016, the total cultured production in Norway was 1,326 thousand tonnes and the corresponding figure for Vietnam was 3,625. Even though Norway produced a smaller amount compared to Vietnam, it is ranked as the second largest exporter in the world, reaching USD 10.8 billion and 7.1 percent. Vietnam, with exports of USD 7.3 billion, is the world's third largest exporter. The main species for aquaculture in Norway is salmon, whereas most of the export revenue in Vietnam comes from shrimp and the white fish pangasius. Aquaculture is thus a significant industry in the two countries, contributing to income, jobs, food security, and nutrition.

Shrimp have been cultured in Vietnam since the 1990s. Since that time, the industry has developed rapidly and become a significant contributor to the country in terms of income generation, employment, food security, and nutrition. The growth performance of this sector was reflected in the increase of the farming area for shrimp from 93,000 ha in 1990 to 721,100 ha in 2017 (VASEP, 2018). In that year, total brackish water shrimp production in Vietnam was estimated at 683.4 thousand tonnes valued at USD 3.15 billion, with a contribution of 50 percent in total export value of seafood products. Shrimp were exported to more than 90 markets, of which 95 percent of the volume goes to the US, the EU, Japan, China, South Korea, Australia, Canada, ASEAN, Taiwan, and Switzerland. Currently, 11.4 percent of the total shrimp production is eco-labelled and certified by the agencies and standards, such as Best Aquaculture Practices (BAP), the Aquaculture Stewardship Council (ASC), GLOBALG.A.P. Aquaculture Standard, and, for organic products, Naturland.

WLS is one of the main commercial-oriented cultured species, which was encouraged by the government in 2006. The practice of WLS aquaculture is popular in the Central and the South of Vietnam. In 2014, there were 98,866 ha under operation and this represented 5.9 percent of the total aquaculture area. Even though the area devoted to farming is modest, it achieved 324,581 tonnes, which accounts for 27.3 percent of the total aquaculture production.

At present, shrimp farms operate as extensive, semi-intensive, and intensive farming systems. These three systems are classified mainly based on the levels of inputs such as stocking densities, water use, feed and chemicals used, and levels of outputs. In addition, integrated farming systems are also broadly practised, such as rice-cum-fish, rice-cum-prawn, and mangrove-cum-aquaculture. The nature of extensive farming means it requires less stocking densities, casual feeding, and tidal water exchange surpassed. Water was mainly pumped, with limited exchange, and the feed is in wet form. With intensive farming, stocking densities are higher, feed is in manufactured pellet form, water is exchanged more often and a greater percentage of chemicals is used. The semi-intensive farming is operated somewhere in between extensive farming and intensive farming.

However, aquaculture in Vietnam is still small-scale with free-entry into farming. The coastal spatial planning was applied in some regions recently and, accordingly, all the new and old farms are obligated to move into planning areas. However, this strategy has not succeeded due to poor plan, weak implementation, and lack of adequate controls and surveillance (Long et al., 2016). The infrastructure of the farming area is in poor condition, most of the farms are at a household scale, there are few or even no sewage ponds, and culture procedures are not applied properly; therefore, the farms face risks of infectious disease outbreaks as well as environmental pollution. The hatchery production is dependent on the parent stocks, which are imported, and therefore it is hard to control the sources and quality. Several forests have been cut down for shrimp aquaculture, many beautiful beaches are polluted, and the danger of exhaustion and salinization of land and underground water is at stake.

Salmon aquaculture in Norway started as small-scale production in the 1960s and 1970s, and in the 1980s gradually expanded to become an important export industry. In the beginning, the market price of the close substitute wild caught salmon was high and benefited aquaculture that could expand even at a high cost. In 1985 the cost per kg was almost 90 NOK (USD 10.7) per kg, measured in 2016 value, and the production was about 50 thousand tonnes (Fiskeridirektoratet, 2017). Technological change and other cost reducing innovations reduced production cost to 33.86 NOK per kg in 2016. The production in this period increased by a factor of about 25. The salmon price has also come down (with some fluctuations) during this period, but in most years, it stayed well above the average cost and made this industry one of the most profitable in Norway. Note, however, that production costs reached their lowest level about a decade earlier, and from 2005 to 2016 the costs have roughly doubled, measured in nominal values per kg production. Even though we consider inflation, the cost increase is over 60 percent.

Increased feed costs and increased costs for monitoring, prevention and treatment of salmon lice (*Lepeophtheirus salmonis*) are the most important explanations for cost increases. Salmon lice are a natural parasite on salmonids in saltwater in the northern hemisphere. The lice eat skin, mucus, and blood on the fish, and can make large wounds if there are many of them on a fish. The lice costs are still high, at around 5 billion NOK a year in 2016, but the growth in lice costs has decreased (Iversen et al., 2017, pp.47). There are also other costly negative externalities, but it is outside the scope of this paper to estimate such costs.

In Norway, limited entry through licensing has been the main policy instrument from the early 1970s, since the preliminary Aquaculture Law enacted in 1973. All fish farms need a licence to enter and operate in the industry. The present Aquaculture Act entered into force in January 2016, and is followed up by more detailed rules and regulations. Farm size is, since 2005, limited by a maximum allowable biomass (MAB), 780 or 945 tonnes of live biomass, per licence, depending on geographical location (fish capital restriction implying hampered output). When the first regulations through licensing took place in the 1970s, a limit on cage size (capital restriction) was the main instrument to control development, and in 1996 feed quotas (input restriction) were introduced. This required reporting of production and feed consumption data. Throughout the history of salmon aquaculture in Norway, licences have been used to include both technical regulations and input controls with the objective of reducing environmental externalities such as fish escape, parasites, and sludge and nutrient salt emissions (Aarset and Jakobsen, 2009; Liu et al., 2011; Hersoug, Mikkelsen and Karlsen, 2018). Aquaculture licences are transferable between firms, but there is a limit (40 percent) to how much one firm may acquire. A licence, for MAB, allows the establishment and operation of a farm, provided an approved location is available, but this is not a real property right for a given space in the coastal zone. The location is allowed as long the licence is used for actual operation within the legal limits of laws and regulations. Nevertheless, a licence and a good location can be worth about 100 million NOK (USD 12 million, 2018) (B. Hersoug, UiT – The Arctic University of Norway, personal communication).

4. RESOURCE RENT IN SHRIMP AND SALMON PRODUCTION

4.1 Data

Both primary data and secondary data are used. Regarding the Norwegian salmon case, we use 2016 data from the Directorate of Fisheries of 84 firms, representing 68.3 percent of the active licences. With respect to the Vietnamese WTS case, data is based on the synthetic results of Long et al. (2016) for 318 farming households that took place in 2014. These households are in four regions of the South-Central Vietnam: Quang Ngai, Khanh Hoa, Phu Yen, Ninh Thuan, and operate on 6,922 ha, representing 79.4 percent and 7.5 percent of the farming area of the South-Central's population and the whole country, respectively. Since the cost and earning data 2014 at farm level is not available, we used cost and earning data of 120 farming households in 2016 in Phu Yen province to allow us explore and compare the Ricardo rent and Faustmann site values of the heterogeneous farms in the two countries.

4.2 Results

4.2.1 Resource rent

Based on the data, total natural resource rent for salmon and shrimp is calculated in Table 1. This is the combined Ricardo and market rent. We shall return to the disentangling of these two and to the Faustmann rent.

Table 1. Resource rent in aquaculture (RRA); The salmon industry in Norway 2016 and the white leg shrimp industry in four provinces of Vietnam 2014

Concept	Explanation	Norway Million NOK (million USD)[2]	Vietnam[3] Million VND (million USD)[4]
Revenue	Farm gate value of sale of fish.	50,072.3[5] (5,961.0)	19,333,146.0 (904.3)
– Total operating expenses	Including recruits, feed, chemicals, medicine, labour, energy, slaughter, maintenance, and depreciation of farm, licence, and permit.	32,035.0 (3,813.7)	17,478,050.0 (817.5)
= Operating profit (EBIT)	Earnings before interest and tax.	18,037.3 (2147.3)	1,855,096.0 (86.8)
+ Total financial revenue	Financial income and currency gains.	530.7 (63.2)	0.0
– Total financial expenses	Financial cost and currency rate losses.	495.4 (59.0)	0.0[6]

[2] Exchange rate (transfer rate) 30/12/2016: 8.4 NOK/USD. This rate is applied to Tables 2 and 3.
[3] The figures are calculated based on the average figures per ha multiplied by the total aquaculture area of the four regions
[4] Exchange rate (buying rate) 30/12/2014: 21,380 VND/USD. This rate is also applied for Table 2.
[5] Almost 90% is Atlantic salmon, the remaining is trout. Based on the 84 firms reported in the Directorate of Fisheries, 2017. They have 743 licenses out of the population of 1088.
[6] As the shrimp farmers do not export shrimp directly to the international markets, financial cost due to currency loss does not occur. Some farmers have private loans outside the banking sector, but data on interest payment is lacking.

= Profit on ordinary activities before tax (EBT)		18,072.6 (2,151.5)	1,855,096.0 (86.8)
+ Depreciation on intangible capital	Intangible capital includes licences and permits (1.5).	-12.5[7] (-1.5)	0.0
+ Financial cost of intangible capital	Financial cost (interests, fees) of licence and permit purchases.	226.5[8] (27.0)	0.0
– Calculated interest on equity	The interest rate should equal what is paid on long-term loans, or equal to interest on government bonds (opportunity cost).	917.6 (109.3)	362,989.7[9] (17.0)
= RRA unadjusted	The residual for the aquaculture industry owners, without deduction of environmental and management cost.	17,369.0 (2,067.7)	1,492,106.3 (69.8)
Operating margin	EBIT in percent of revenue.	36.0	9.6
Net profit margin	EBT in percent of revenue	36.1	9.6
Resource rent margin	RRA in percent of revenue	34.7	7.2

Sources: Flaaten, Heen and Matthíasson, 2017. Data Norway: Fiskeridirektoratet (2017); Knut Heen, UiT – The Arctic University of Norway (personal communication); Data Vietnam: Long et al. (2016)

Table 1 presents the economic performance of salmon and WLS farms. The resource rent margin is 34.7 and 7.2 for the Norwegian and Vietnamese case, respectively. We observe about the same pattern for the net profit margin. In both cases, the resource rent margin with RRA is slightly lower than the net profit margin, mainly due to the calculated interest on equity. The same applies when comparing with the operating margin. Differences in market power may be a major explanation of the difference in performance between the two resource industries. We will return to this in the Discussion section. For economic efficiency comparison, the indicators in Table 1, with revenue in the denominator, have some deficiencies. An alternative, usually recommended in business economics, is to use capital in

[7] It is a bit odd that this number is negative; purchases of farms/licenses with negative goodwill may be an explanation (Fiskeridirektoratet, 2017).
[8] Based on 4% real annual rate of interest recommended by the Ministry of Finance as opportunity cost of capital in long-term public investment projects.
[9] Interest rate is 12% per year.

the denominator. Capital and return rates are demonstrated in Table 2, with five types of capital; fixed assets, intangible fixed assets, financial fixed assets, fish capital – live and processed, and other current assets.

Table 2. Capital and return rates; The salmon industry in Norway 2016 and the White leg shrimp industry in Vietnam 2014

Capital, 31st December	Explanations	Norway	Vietnam[10]
		Million NOK (Million USD)	Million VND (Million USD)
Total tangible fixed assets	Including land, buildings, and other real property, plant and machinery, operating equipment	9,928.4 (1,181.9)	11,663.6 (0.55)
Intangible fixed assets	Including licences and goodwill reported in the firm accounts	6,563.2 (781.3)	0
Financial fixed assets	Including ownership/shares in other firms – aquaculture and others	3,699.4) (440.4)	0
Fish stocks	Live and processed	16,413.1 (1,953.9)	9,666.6 (0.45)
Other current assets, excl. fish stocks	Including receivables, investments, bank deposits, and cash at bank	18,218.6 (2,168.9)	0.0
Total assets		54,822.7 (6,526.5)	21,330.1 (0.99)
Return on total assets (ROC) (profit rate)	EBT + financial expenses in percent of total assets (equals EBIT plus financial income in percent of total assets)	33.9	87.0
Resource rent rate (RRR)	Unadjusted RRA in percent of total minus intangible assets	36.0	70.0

Sources: NORWAY: Fiskeridirektoratet (2017); Knut Heen, UiT – The Arctic University of Tromsø (personal communication); VIETNAM: Long et al. (2016); Long Le Kim, University of Nha Trang, Vietnam (personal communication)

The business economic indicator ROC in Table 2 tells how effectively a farm utilizes its capital assets to generate profit and remuneration of the external capital. However, for shrimp in Vietnam, the assets are very low in value compared to the operating expenses, notably seed, feed, electricity, and labour. Therefore, traditional capital return indicators, such as ROC as well as RRR, are hardly useful in this case as they reach unbelievable values. The

[10] The figures are calculated based on the average figures per ha multiplied with the total area of the four provinces.

indicator RRR is closer to a welfare economic indicator, excluding the private value of purchased rights, etc. from the calculation, but also this has the capital in the denominator. In conclusion, for a developing country with relatively little capital in the aquaculture production process, indicators based on return related to revenue are probably better indicators for intra- as well as inter-industry comparison of firm performance.

4.2.2 Ricardo rent

Based on the theoretical discussion and the data, Heckser-Salter figures are shown in Figures 3 and 4 for salmon and shrimp, respectively. These figures illustrate the cost-efficiency of heterogeneous salmon firms and shrimp farms in Norway and Vietnam in 2016. The width of the bars shows the relative production. This is measured by the production of each farm divided by average production of all the farms; thus, the total production is equal to the number of farms surveyed. In Vietnam, the total relative production is 120 and this figure is 83 for Norway. The height of the bars measures the average cost per kg for each farm. The average total cost includes smolt, seed, feed, chemicals, insurance, slaughter, labour, depreciation, and others. The upper horizontal line AR presents the average revenue per kg, and the lower AR is estimated for the competitive market.

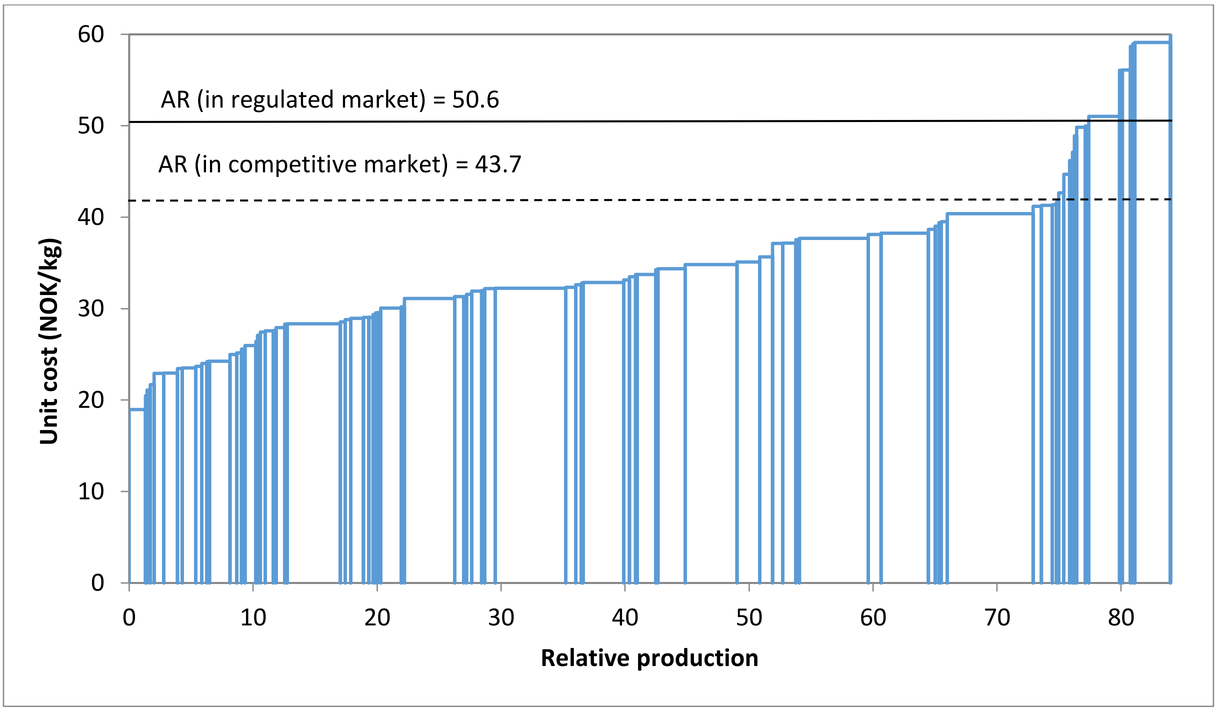

Figure 3. Cost-efficiency of 83 Norwegian salmon firms in 2016[11]

[11] Note that one farm is excluded due to some unexplained anomalies regarding cost and production.

Data source: Directorate of Fisheries, 2017.

Figure 3 indicates that few of the Norwegian firms have a unit cost higher than the average revenue, whereas in Figure 4 this is not so in Vietnam, where about one-third of the farms have higher unit cost than unit revenue. In Figure 3, the bigger firms are scattered somewhat arbitrarily along the x-axis, and not leaning to the left, indicating that the notion of "big is beautiful" may not hold in this case. This is somewhat in line with what was reported by the Directorate of Fisheries (2017). In contrast to the Norwegian salmon case, some of the large shrimp farms seem to make better profits than the small ones (Figure 4). This does not contradict the Norwegian case, "big" farms here are still very small compared to Norwegian farms, in particular regarding production and capital.

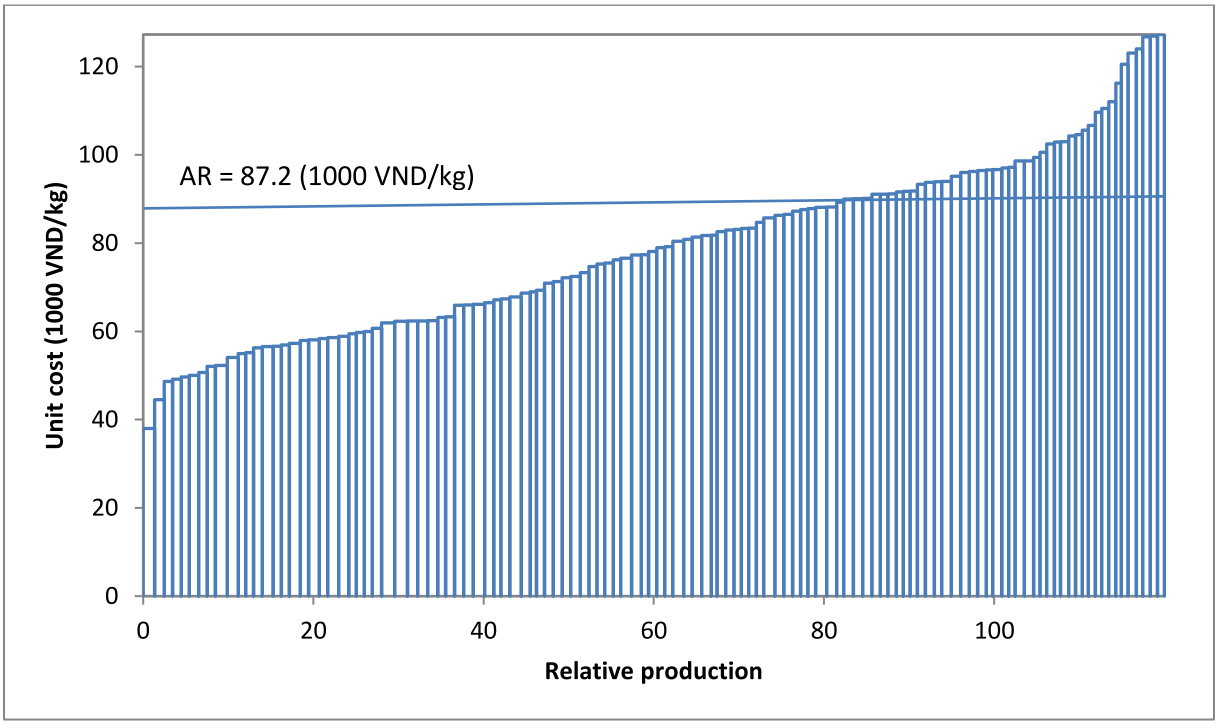

Figure 4. Cost-efficiency of 120 shrimp farms in Vietnam in 2016

Data source: Own data

Since both Vietnamese farms and Norwegian firms differ with respect to cost, they may also differ with respect to revenue. A correlation analysis between unit cost and unit EBIT may give an indication. The correlation coefficient between unit cost and unit EBIT is

−0.89 and −0.79 at 1% significant level, for shrimp and salmon, respectively. Figures 5 and 6 give the graphical pictures of how cost and operating profit vary across firms. For example, in Norway, firm 4 has unit costs smaller than the average revenue but it has negative EBIT, whereas firm 10 with unit costs above the average revenue produces more valuable fish than the average and hence makes a good profit. The same also applies to Vietnamese shrimp producers, where 48 farms have unit costs higher than average revenue, but three of them have positive unit EBIT and one breaks even. Two farms receive a loss even though they have lower unit costs than the average revenue. The survey shows that many farmers use bio-products recently as inputs, and therefore there are fewer diseases for shrimp and higher production as a consequence.

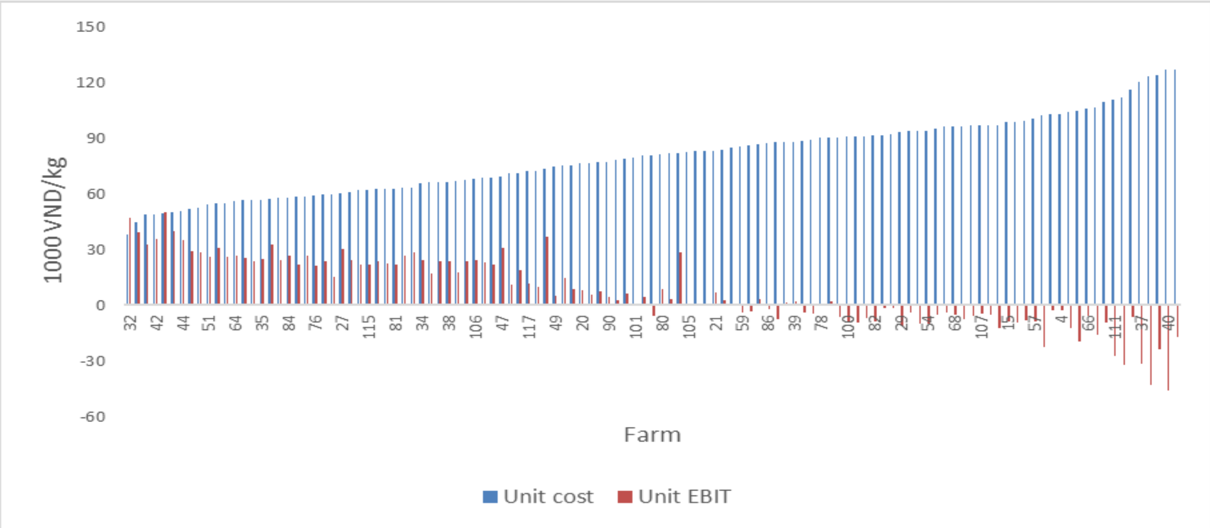

Figure 5. Unit cost and Unit EBIT of 120 shrimp farms in Vietnam in 2016

Data source: Own data

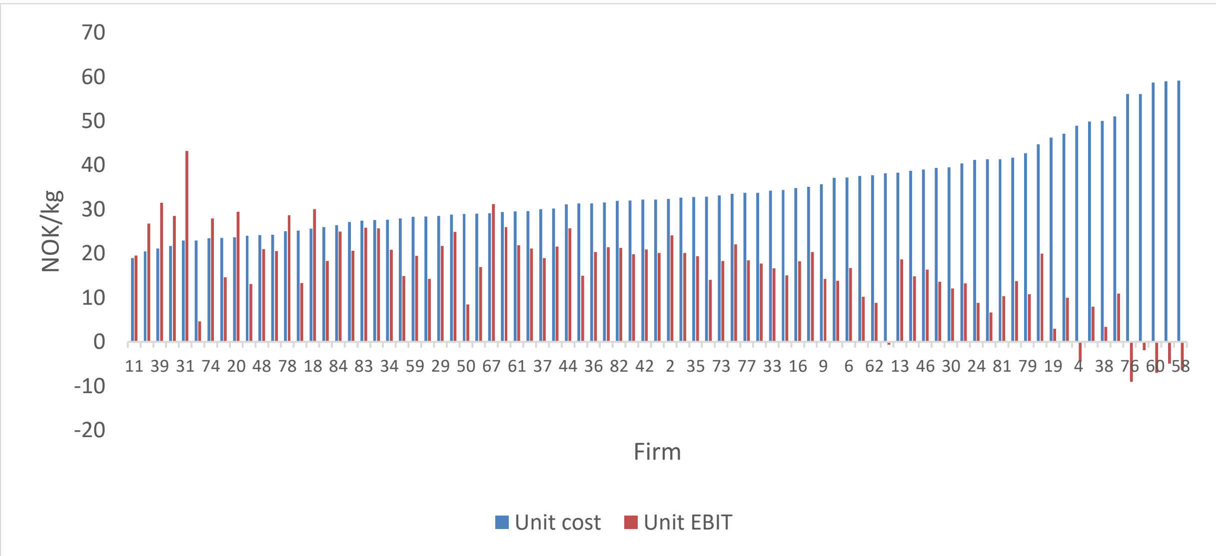

Figure 6. Unit cost and Unit EBIT of 83 salmon firms in Norway in 2016

Data source: Directorate of Fisheries, 2017.

4.2.3 Market rent

Norwegian-produced Atlantic salmon has more than half of the world market, and a downward sloping demand exists (Brækkan, 2014; Brækkan et al., 2018). Thus, limits on Norwegian production have an effect on the world market price and the revenue of own salmon farms.

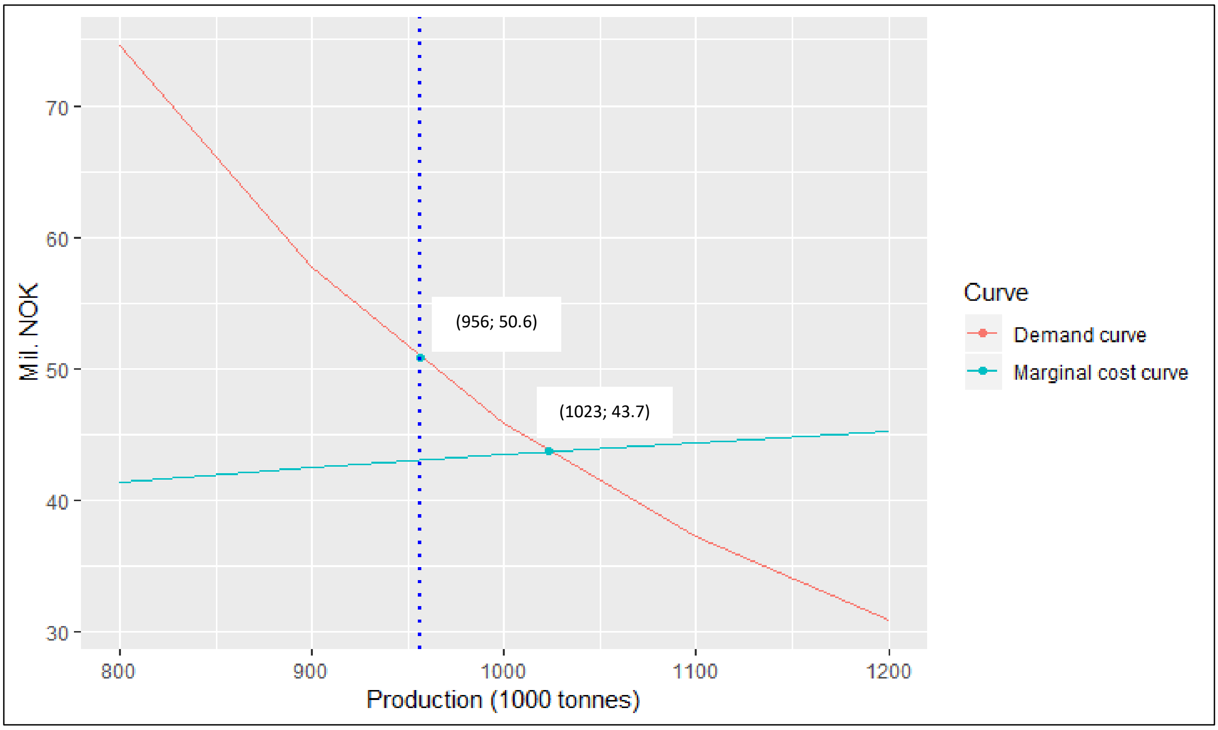

Figure 7. Market rent of Norwegian salmon industry in the competitive and regulated markets.

Using a constant elasticity demand function $Q = AP^{\varepsilon}$, with the 2016 figures Q=956 thousand tonnes, P=50.6 NOK per kg, and ε=−0.46, we derive the demand curve of Norwegian salmon[12] $Q = 5812 * P^{-0.46}$. The elasticity of demand is −0.46, borrowed from Brækkan (2014) who estimates, within a world market model, that a one percent increase in Norwegian salmon production reduces the world market price by almost half a percent.

[12] Includes trout production. The 2016 revenue, *PQ*, in Figure 7 is slightly lower than the revenue in Table 1, since the latter includes other operating revenues, such as insurance compensation, sale of roe and feed, as well as rental income.

The industry marginal cost curve is assumed to have power shape, with the estimated function $MC(Q) = 2.232 * Q^{0.223}$. The function is simulated using 83 Norwegian salmon firms where data for *MC* is the unit cost of 83 firms, and *Q* is the cumulative production from the most efficient firm to the least efficient firm. In the competitive market, the equilibrium price and quantity are, by assumption, at the intersection of the demand and the cost curves, equal to 43.7 NOK/kg and 1023 thousand tonnes. However, the current average price in 2016 is recorded to be higher (50.6 NOK/kg) and the quantity sold is less (956 thousand tonnes) than those in the competitive market. This implies that there might be market power in the regulated market, benefiting the Norwegian salmon firms. The market rent is defined as the area created by the additional price gained due to restriction of the entry multiplied by the quantity sold (Figures 2 and 7).

Shrimp exports from Vietnam are about ten percent of the world market and, to the best of our knowledge, there are no indications in the literature that this industry achieves any market rent.

4.2.4 Faustmann rent and site value

Faustmann rent per salmon farm is calculated based on the formula for the site value, $\frac{V(t)}{e^{\delta t}-1}$, discussed above, and on an annual interest rate of 8 percent, as well as the optimum age of harvest 680 days (Figure 1 and Annex). The same principles have been used for Vietnamese shrimp farms, based on the optimal age of harvest, equal to 112 days per cycle with three cycles per year (Wijayanto et al., 2017), adjusted to 122 days to take into account the fallow days for rest, cleaning, and repair. The annual interest rate is 12 percent, reflecting the market rate in 2016.

On average, the Faustmann site value per salmon firm is 1,220 Million NOK. As discussed above, Faustmann rent partly consists of and is affected by Ricardo rent and market rent, but does not come as a rent in addition to these two. There is a great variation in site value among the salmon firms and this is illustrated in Figure 8. As can be seen in Figure 8a, some of the salmon firms have extremely high site value, whereas others have nothing. The latter ones tend to fail against the least cost-efficient group.

The result indicates that the values are also varied among the groups. The value is approximately 910.0 Million NOK per firm on average for the high cost-efficiency group. This is almost double for the average one (1,512.6 Million NOK), and around two-thirds for the low one (623.7 Million NOK). It is noted that the average group has almost the same median value compared to the high group and its third quantile is large. This indicates that site values of the average group are rather varied, some have a lot while others have little.

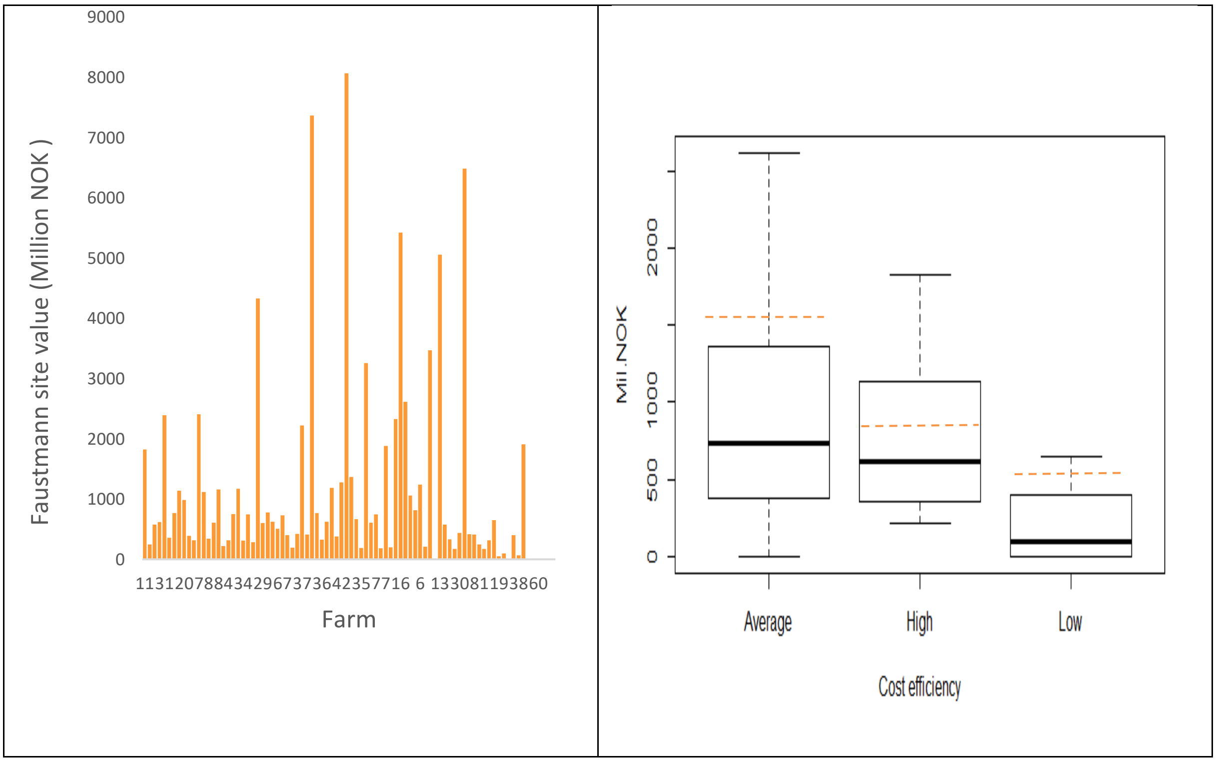

Figure 8. Faustmann site value of the Norwegian salmon firms. Figure 8a) per firm, ranking from the most cost-efficient one to the least cost-efficient one; Figure 8b) of the three cost-efficient groups: High is for 17 most cost-efficient firms; Average is for 49 middle cost-efficient firms; Low is for 17 least cost-efficient firms. The boxplot displays the site value of the three groups with minimum, first quantile, median, third quantile, and maximum value. The red dashed line is the average group site value.

Figure 9 illustrates the resource rent (Ricardo and market rent) in each of the 83 Norwegian salmon firms, ranking from the most cost-efficient to the left to the least cost-efficient to the right. Note that firms with middle cost-efficiency seem to have higher resource rent than those that have low or high cost-efficiency. This group captures both market rent and Ricardo rent, whereas the high cost-efficient group to the left seems to have more Ricardo rent than market rent. The least cost-efficient ones to the right have a small amount of resource rent, and this comes mainly from market rent and hardly anything from Ricardo rent.

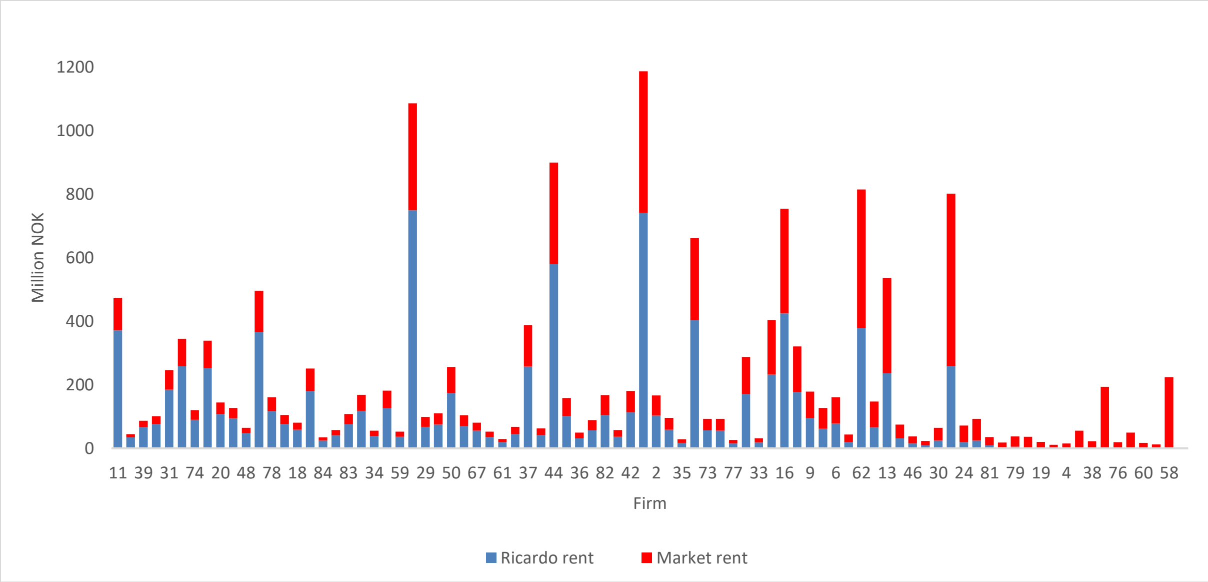

Figure 9. Resource rent of 83 Norwegian salmon firms, 2016.

In contrast to the Norwegian salmon industry, the Faustmann site value of Vietnamese shrimp farming is relatively small, with only 1,338 Million VND (60,000 USD) per farm on average. The distribution of resource rent, in this case only Ricardo rent, across the Phu Yen farms, is shown in Figure 10. Many farms do not gain any site values. The value is likely to decrease when the farms are less cost-efficient (Figure 11a). This is further illustrated in Figure 11b. Particularly, the site value of the high cost-efficient group is equal to 3,240 Million VND per farm on average and ranked as the highest value group, following by the average group with 700 Million NOK, and the low one with least cost-efficiency has no value. The pattern is different from that of the Norwegian case, because the shrimp farms have been operating in a competitive market, and therefore the market rent is depleted and the Faustmann site value follows the pattern of the Ricardo rent as a consequence.

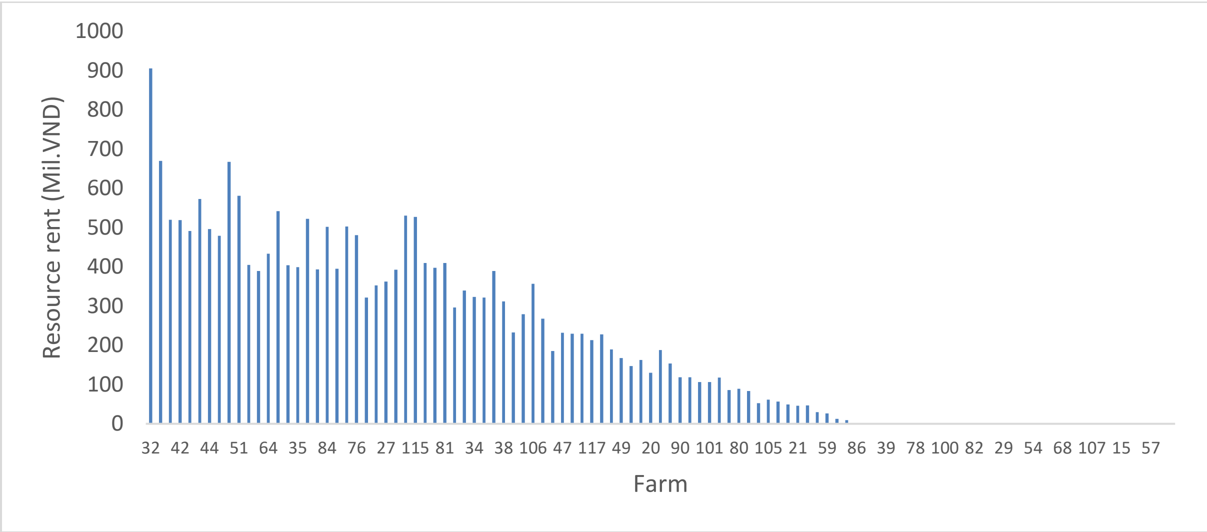

Figure 10: Resource rent of the Vietnamese shrimp farms

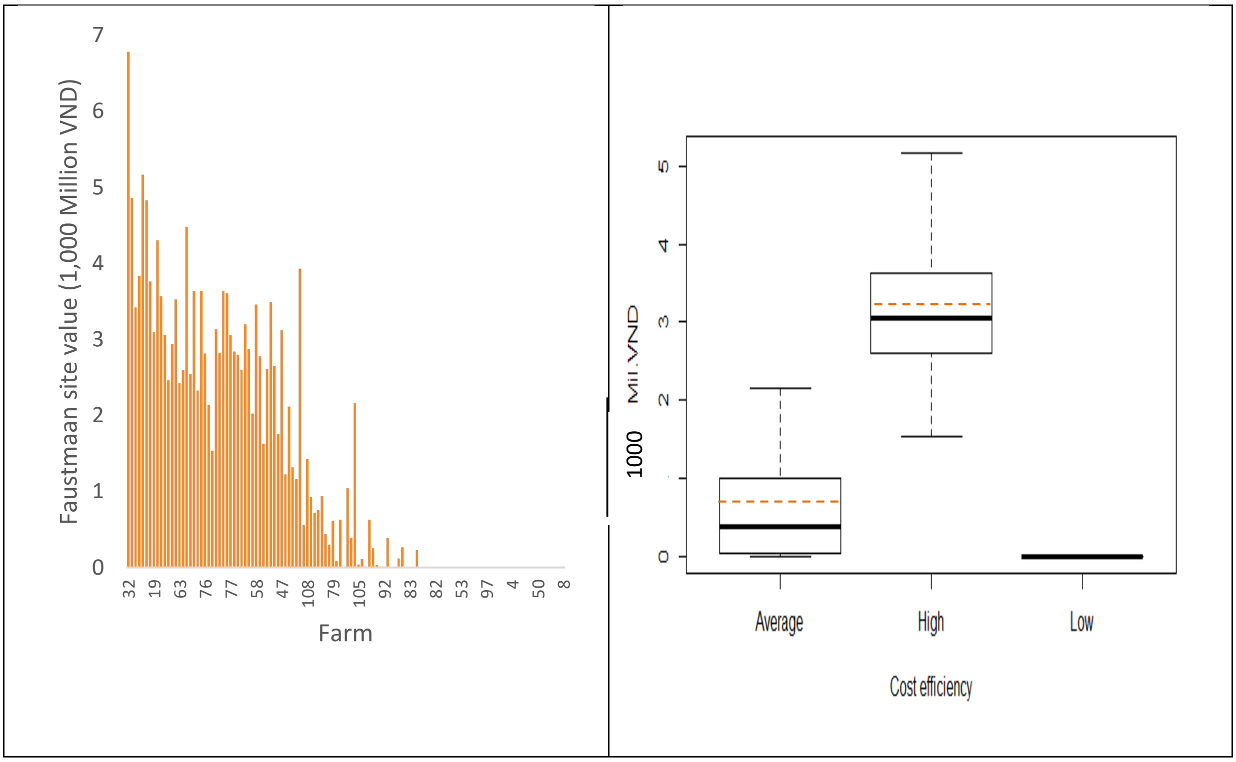

Figure 11. Faustmann site value of the Vietnamese shrimp farms based: Figure 11a) per farm, ranking from the most cost-efficient one to the least cost-efficient one; Figure 11b) of the three cost-efficient groups, and each group consists of 40 farms. The boxplot displays the site value of the three groups with minimum, first quantile, median, third quantile, and maximum value. The red dashed line is the average site value for each group.

4.2.5 Rent summary

Table 3 summarizes the types of resource rent for the surveyed salmon firms and shrimp farms in 2016, as well as the average Faustmann rent per firm/farm.

Table 3: Summary of rents in the surveyed Norwegian salmon firms and Vietnamese shrimp farms, 2016

Rent type	Norway Million NOK (Million USD)	Vietnam[13] Million VND (Million USD)[14]
Market rent (1)	6,596 (785.23)	-
Ricardo rent (2)	9,177 (1,092.50)	21,785 (0.96)
Resource rent (1+2)	15,774 (1,877.86)	21,785 (0.96)
Faustmann rent per firm	97.6 (11.61)	160.6 (7.07^{-3})
Faustmann site value per firm	1,220 (134.56)	1,338 (0.06)

5. DISCUSSION

The economic performance analysis of the salmon industry in Norway includes 84 firms with 743 licences out of the population of 1088, and is considered representative for the national industry (Directorate of Fisheries, 2017). The first two tables include, for Vietnam, data for WLS in four provinces, and as such, the material is considered representative. However, shrimp production also comprises other species than WLS, mainly tiger shrimp (*Penaeus monodon*), and several other provinces than the four. Even though the revenue and cost data in Table 1 is limited in scope, we think the performance indicators are close to the truth for the shrimp industry, even though not necessarily statistically representative for the whole country.

[13] Based on 2016 data for 120 farms in Phu Yen province.
[14] Exchange rate (buying rate) 31/12/2016: 22,720 VND/USD.

As demonstrated above the RRA and the profitability for salmon in Norway in 2016 was very high. Despite a declining market share since 2010 this country still has more than half of the global market for aqua cultured *Salmo salar*. With more than 50 percent of the world Atlantic salmon supply,[15] this gives the industry as a whole opportunity to affect the price. Restricted production through the licensing system and environmental regulations have gained the industry market rent. Even though the production and export have increased for more than three decades, demand has risen steadily and outpaced supply (Brækkan, 2014; Brækkan et al., 2018). Increased output and increased price simultaneously is very rare in international trade, but nevertheless occurred for salmon and made the Norwegian industry very profitable from the market rent gain. As a contrast, Vietnam has a market share of about ten percent for shrimp in the world market, which is much less than the more than 50 percent Norway has for salmon. Thus, Vietnam faces a greater competition and it is hard to influence the price positively in the world market. The open-access strategy for aquaculture in Vietnam also leads to very limited restriction on entry of farms and production.

The average Faustmann site value of salmon firms equals 1,220 million NOK (134.6 million USD) in Table 3. With an average of 8.85 licences per firm, this corresponds to a site value per licence of about 138 million NOK in 2016. Compare this to the statement "a licence and a good location can be worth about 100 million NOK (USD 12 million, 2018)" given above. This discrepancy indicates that salmon firms use a higher discount rate than the eight percent used for Table 3, reflecting the uncertainty regarding i.e. governmental regulation and taxation (see below). It could also be that the industry estimates higher future costs and lower market price than the historic averages used for Table 3. Of course, it could be that other experts would have given higher value estimates than 100 million NOK; transfer prices are not officially recorded. Overall, the findings in this paper match reported market values of licences pretty well.

With de facto supply restriction of all the Norwegian salmon firms, each of them would gain from an own expansion, especially when price is significantly higher than marginal cost. This puts pressure on the regulatory system with monitoring, control and enforcement (MCE) of more than one thousand locations. It is also not straightforward to tell if the facilities in one location contain more or less than the MAB quota of 780/945 tonnes of

[15] In 2010, Norway produced 65.4 percent of the world's farmed Atlantic salmon. In 2014 its market share had fallen to less than 53 percent, but stayed at about this level until including 2017 (https://salmonbusiness.com/norways-market-share-shrinking/ downloaded 12 November, 2018).

live fish. In addition, there is a limit on the average number of female lice per salmon, as well as other environmental regulations related to such as vaccination of fish, disease treatment, fish escape, and cleaning of nets. Management and environmental costs are not deducted from the calculated resource rent; although this is important, it is left for future research. For salmon lice, control cost for the firm is included in operating costs. Still, it does not account for negative effects for wild fish, shrimp etc. Access regulation with transferable licences and permits imply industry accumulation of intangible capital, but in the firm accounts for 2016, this type of cost is relatively small compared to the additional revenue gained from higher export prices.

If environmental external costs were included, the RRA would have been lower. In the case of Vietnam, it might come closer to zero (Long et al., 2016). This because shrimp aquaculture is considered to cause environmental problems, such as mangrove deforestation (Barbier & Cox., 2004), chemical and waste discharge, and spread of disease and parasites (Huy & Maeda, 2015; Hedberg et al., 2018). The survey (Long et al., 2016) shows that most of the farms do not have waste treatment systems and the waste discharges directly into the coastal area. Even though large shrimp farming enterprises normally have waste treatment systems, the systems are still very modest. According to field surveys in all four provinces in 2014, the farmers often use ground water in coastal areas due to surface water pollution. The water is processed through a settling pond system before being used. The intensive shrimp farming is relatively costly and faces significant risk during the production period. Therefore, it is not surprising that most shrimp farmers respond that water pollution is the main risk in the South-Central region (Long et al, 2016).

Generally, economy of scale of the farms helps reduce cost per unit and improves margins, and thus return may grow at a faster rate than assets, ultimately increasing return on assets. However, Table 2 shows that even though the Vietnamese shrimp farms are much smaller than the Norwegian ones, the relative return on total assets in Vietnam is 2.8 times higher than in Norway, although we have raised some concern about use of capital related indicators when capital intensity differ between industries. To investigate the economy of scale across industries and countries is not a straightforward exercise and shall not be pursued in this paper (Asche et al., 2013 could be a point of departure).

As noted above, there is a decreasing trend of the WLS industry in the South-Central Vietnam. The area used dropped from 6,222 ha in 2010 to 4,846 ha in 2014, and the production has been reduced by 11.7 percent during that period (MARD, 2015). The rapid development of intensive WLS farming has, after a short expansion period, led to inefficient use of inputs of production. In the long run, this resulted in adverse effects on the growth and sustainable development. Consequently, many shrimp farms went bankrupt and had to leave the industry. Polluting emissions from shrimp culture, mainly nitrogen (from faeces and excess feed) and antibiotics, have altered local ecosystems and led to water pollution. Contaminated water is considered the main cause of disease outbreaks and drug resistance as happened in 2012 and 2013 on the South-Central Coast (Long et al., 2016). Whereas the intensive farming model tends to reduce the area needed, the area of semi-intensive farming, which is considered less pollutant, has increased, and more than doubled from 2,288 ha in 2010 to 4,772 in 2014.

The Norwegian Parliament and Government have both expressed interest in using taxes to capture a share of the resource rents in aquaculture, as have been done for other natural resources such as oil and gas, hydroelectric power, and mineral ore. As demonstrated in this paper, the salmon industry has benefited Ricardo and market rents from regulations, increasing the Faustmann site values to very high levels. For the policy makers and the public, this has created a debate about environmental issues, efficiency, and equity. Environmental issues have been touched upon above. The efficiency issues can be by questioned when initial allocation of land and sea space is done for free and the conditions for the Coase theorem to work are not fulfilled. For instance, initial occupiers can determine how to use the land, and since land costs nothing, the opportunity cost is normally not fully considered. The equity dimension is discussed when the property right to resources does not accrue to the public at large but to a limited number of private firms. The Norwegian Government, partly based on proposals from the Parliament, is considering introducing some kind of resource taxation for the aquaculture industry and in September 2018 appointed a committee to assess, within a year or so, the taxation of aquaculture.[16] The issues are, however, not new in the policy discourse. Very modest taxation of aquaculture expansion was introduced from 2002, and in 2017-18 some additional production capacity was sold through auctions.[17] Of course, aquaculture firms pay ordinary profit tax, local property tax, etc., when appropriate.

[16] https://www.regjeringen.no/no/aktuelt/dep/fin/pressemeldinger/2018/utvalg-skal-vurdere-beskatningen-av-havbruk/mandat-for-utvalg-som-skal-vurdere-beskatningen-av-havbruk/id2610382/

[17] https://www.regjeringen.no/no/aktuelt/lakseauksjonen-er-fullfort/id2605186/

6. CONCLUSION

The discussion of types of rent in aquaculture concludes that market rent and Ricardo rent are the essential ones to consider in this case. Based on this, the Faustmann rent and site values are discussed. However, market rent exists only when an aquaculture industry has some market power for its products, such as for Norwegian salmon, which serves more than half of the world's market. Vietnamese shrimp has a much lower market share, about ten percent in a very competitive world market, and the farms, on average, hardly generate any resource rent. Faustmann rent varies among farms, and is affected by market conditions and regulatory regimes, in addition to biophysical conditions underlying the Ricardo formula.

Business economic and welfare economic indicators are discussed and compared, as well as calculated for the two industries. The performance indicators have either revenue or capital in the denominator. Since Vietnam has relatively little capital in shrimp production, indicators based on capital are very high; ROC and RRR equal 87.0 and 70.0 percent, respectively. For Norway, these two indicators are 33.9 and 36.0 for ROC and RRR, respectively; still very high compared to other industries in Norway, but much lower than for shrimp in Vietnam. On the other hand, the net profit margin and resource rent margin for salmon are 36.1 and 34.7 percent, respectively. This is much higher than the corresponding figures of 9.6 and 7.2 percent for the WLS in Vietnam. Salmon production is very capital intensive and shrimp production is a low capital industry for the two countries discussed, and these factors cause the anomalies between indicators based on capital and revenue.

The salmon industry in Norway generates huge resource rent due to constraints on production and export, partly due to government licensing and partly due to fish diseases, including the lice parasite, and high mortality that hampers production. In contrast, Vietnam does not use licences and the entry and exit conditions for shrimp farms are close to that of a fully competitive industry. With a relatively little market share it is also a question whether export restriction could influence prices positively. The challenges ahead may rather be in quality improvements, both in products and in production processes to improve local environmental conditions. Studies of seafood and other food product markets have indicated that greening may be beneficial for both consumers and producers. The Vietnamese shrimp production is an interesting candidate for further studies.

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Annex

Rotation – Faustmann rule

At the beginning of each rotation, when juveniles are released into the cage, the present value for that particular rotation is $\Pi(t) = V(t)e^{-\delta t}$. Since all rotations are of the same length (for constant parameters across time), the present value of the profit of n rotations at the time of release of the first cohort is

(A1) $\pi_n(t) = V(t)e^{-\delta t} + V(t)e^{-2\delta t} + \cdots + V(t)e^{-n\delta t} = V(t)e^{-\delta t}(1 + e^{-\delta t} + e^{-2\delta t} + \cdots + e^{-(n-1)\delta t}) = V(t)e^{-\delta t}A,$

where

$$A = 1 + e^{-\delta t} + e^{-2\delta t} + \cdots + e^{-(n-1)\delta t}$$

In principle the number of rotations is unlimited, and we use $\lim_{n\to\infty} A = \frac{1}{1-e^{-\delta t}}$.

For the infinite horizon case

(A2) $\pi_n(t) = V(t)e^{-\delta t}\frac{1}{1-e^{-\delta t}}$.

Using the first order condition for the maximum of $\pi_n(t)$ the Faustmann rule can be derived

(A3) $V'(t) = \delta V(t) + \frac{\delta V(t)e^{-\delta t}}{1-e^{-\delta t}} = \delta V(t) + \frac{\delta V(t)}{e^{\delta t}-1}$.

The rotation problem was formulated by the German forester M. Faustmann in 1849, and was simplified and solved mathematically in Pressler (1860). An alternative way of writing (A3) is on the relative form

(A4) $\frac{V'(t)}{V(t)} = \frac{\delta}{1-e^{-\delta t}}$.

Further, we may use the capital growth when the value of fish at time *t* depends on individual weight *w(t)*, number of fish *N(t)*, and price of fish *p(t)*. Using this in the Faustmann rule (A3) and (A4), suppressing time *t*, and assuming constant price of fish, *p'(w)=0*,

(A5) $\frac{w'(t)}{w(t)} = \frac{\delta}{1-e^{-\delta t}} + M,$

is the Faustmann rule in aquaculture with fish growth and in the presence of natural mortality.

Fish growth

The stylized logistic salmon growth used for Figure 1 is

(A6) $$w(t) = \frac{w_\infty}{\left[1+\frac{w_\infty - w_0}{w_0}e^{-rt}\right]} = \frac{w_\infty}{[1+ke^{-rt}]}$$

(A7) $$\frac{w'(t)}{w(t)} = \frac{\frac{w_\infty - w_0}{w_0}r}{\left[\frac{w_\infty - w_0}{w_0}+e^{rt}\right]} = \frac{kr}{[k+e^{rt}]},$$

w(t) is the weight of fish at age *t*, *w'(t)=dw(t)/dt*, w_∞=maximum weight of fish, w_o=weight of recruits (smolt) at release time *t=0*.

Parameters for Figure 1; derived to yield an approximation to the actual growth situation for Norwegian salmon in 2015, using findings in Jobling (2003), Olsen and Hasan (2012) and Thyholdt (2014), though excluding seasonal growth.

	Symbol	2015~rounded used
Intrinsic growth rate, per day	*r*	0.009
Maximum weight of fish	w_∞	16.0 (kg)
Weight of recruits	w_0	0.12 (kg)
Relative growth potential after release	$k = \frac{w_\infty - w_0}{w_0}$	
Price of fish	*p*	34.57~34.50 NOK/kg
Interest rate, annual (per day)	δ	0.10 (δ/365)
Mortality rate, annual (per day)	*M*	0.15 (*M*/365)

Source: Flaaten, 2018.