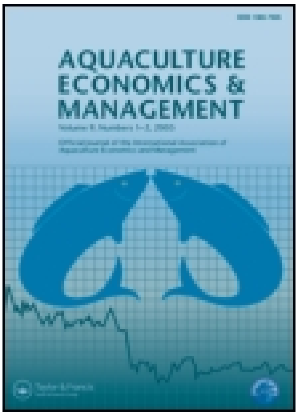

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SPATIAL DIVERSIFICATION IN NORWEGIAN AQUACULTURE

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□ *Salmon farming companies face risks in both production and their markets. These risks provide incentives to diversify production spatially. A spatial diversification strategy can reduce production risk and contractual obligation risks. In this paper, we investigate the feasibility and consequences of geographically diversifying production in Norwegian aquaculture. Our analysis suggests that diversification can significantly reduce fluctuations in returns and reduce sensitivity to local risk factors.*

Keywords diversification, economics of scale, Norwegian aquaculture, production risk

INTRODUCTION

Salmon aquaculture, like most agricultural sectors, is vulnerable to exogenous shocks in the production environment. Disease outbreaks, influxes of algae, temperature changes and extreme weather conditions are sources of both profit risk and supply risk. Such biophysical shocks can have adverse economic consequences for firms in a market where stability of supply is important and where the time it takes to replace lost output is relatively long. For example, a disease outbreak can lead to high mortality and force a farm to harvest its entire stock of remaining live fish. The economic consequences of such outcomes can be substantial, leading to credit downgrading or bankruptcy. Reducing the likelihood of adverse outcomes should accordingly be attractive. Geographical diversification of production units is one option available to firms to reduce risks to returns associated with stochastic shocks to local production environments. By exploiting a less-than-unit correlation between shock occurrences across geographical locations, supply and expected returns can be smoothed over time.

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As aquaculture is becoming the main provider of seafood, the demands from the market for a reasonably stable and predictable supply will increase. Buyers expect aquaculture producers to have a higher degree of control over the production processes than traditional fisheries. Processed aquaculture products are increasingly marketed through large retail chains where there are risks related to retailers' extensive requirements of suppliers in terms of physical deliveries (volume, timing, fish size, quality, etc.), documentation and certification. This is clearly the case for the Norwegian aquaculture industry, the largest global exporter and producer of farmed Atlantic salmon, with an export value of 17.5 billion NOK and a production of 723,000 tons in 2007. Over time, retail buyers have become significantly less tolerant of unpredictability of supply. This development implies that firms that can provide a predictable supply of fish with respect to timing, volume and quality are rewarded increasingly by the market. Reducing large fluctuations in the timing, quantity, size distribution and quality of output can thus increase firm value, and spatial diversification is one potential tool to achieve this.

A trend observed in salmon aquaculture since the early 1990s is increasing market consolidation. Aquaculture firms have merged into multiplant and often multinational corporations (Grindheim, 2008). Integrated firms also own primary processing plants. Possible drivers behind the consolidation process are risk reduction in production and market supply, as well as economies of scale in farming and processing and increased economic benefits from tighter vertical coordination between farming, processing and other stages of the value chain (Asche, Roll, & Tveteras, 2007; Kvaløy & Tveteras, 2008).

The EU is the largest importer of Norwegian salmon, with a share of 63% in 2007. However, in recent years Russia has emerged as an important market, taking 13% of total exports. This makes Russia the second-largest importing country. The growing importance of the Russian market can increase the incentives for diversifying production, as Russia provides the northern parts of Norway with a comparative advantage in transportation cost. The EU and Russian markets can experience different business cycles influencing salmon demand, because, for example, Russia is a large producer and net exporter of oil and natural gas while the EU is a large importer. Spatial diversification between Norway's northern and southern regions may be a hedge against unexpected demand shifts in these markets.

All these factors suggest that geographically diversifying production is an attractive way to reduce profit risk and increase the stability of supply of farmed salmon. The development of the market for Norwegian aquaculture also suggests that spatial diversification can improve the long-run survivability of Norwegian aquaculture firms.

This paper provides an analysis of the potential benefits of risk reduction from spatial diversification strategies in Norwegian aquaculture. We discuss issues relevant to localization of production units in order to reduce returns risk, in addition to evaluating the trade-off between risk and expected returns. Furthermore, the paper discusses other issues that should be evaluated when planning to diversify. The paper provides a model for the evaluation of diversification in production theory, building on the standard portfolio analysis for financial assets. We illustrate how elasticity of returns is related to economic effects of diversified production and discuss how important issues related to economies of scale and agglomeration effects arise when evaluating diversification in the industry.

The formal analysis of these criteria will be based on an approximately linear optimization problem where the desired optimum will minimize variance for a given level of expected returns. From this, we build a vector of minimum-variance portfolios: the efficient frontier, where optima can be located. Our treatment will impose one important restriction on the data generating process. The linear treatment of the problem will necessitate an assumption of constant returns to scale. Constant returns will further imply a quadratic relationship between returns variance and scale of production, in effect assuming a variance independent of the eventual economies of scale effects. This assumption is especially strict, since we know that economies of scale effects are present in the industry (Tveteras, 1999, 2002; Asche, Roll, & Tveteras, 2009). This means that our measures of the risk–returns trade-off from diversifying will be downward biased in the case of cost and variance.

Obtaining specific and precise information on costs and benefits from diversifying is demanding. This is evident in the literature, in which the effects of diversification on firm values are largely uncertain and conditional on specific market and firm characteristics. In our analysis, we will treat production units located in different regions as value generating assets, using a large firm-level panel data set provided by the Directorate of Fisheries. This allows us to construct a portfolio of assets tractable for evaluating trade-offs in expected operating margins and risk. The empirical result indicates that the conditions for diversification are met and that these correlations decrease as the distance between production locations increase. The minimum-variance curve is concave, indicating a significant reduction in returns variance at the cost of reducing mean returns compared with full concentration of production in a single region.

The paper begins with a discussion of diversification in light of production theory and some relevant literature. We then present a discussion of characteristics of the Norwegian aquaculture industry. Next, we present the theoretical foundations for the portfolio analysis and then apply the method to Norwegian aquaculture. Finally, we discuss the results and relaxation of restrictions.

Why Diversify?

Spatial diversification of production is a risk-management tool available to firms. This tool will be especially relevant for firms who value risk reduction to such a degree that they are willing to give up some expected returns. The returns from diversification come in the form of a reduction of profit risk primarily through reduced output risk. However, diversification may also reduce the probability of the extreme positive outcomes so that, on average, diversification generally comes at the cost of reducing expected profits.

In contrast to diversifying a financial asset, diversification of physical production units may incur costs related to the loss of economies of scale and/or agglomeration benefits. A firm that uses fixed and lumpy inputs for which transportation costs are high cannot fully exploit the benefits of focusing its entire production in one location. Diversifying production can lead to overinvestment in businesses with poor investment opportunities (Stultz, 1990; Rajan et al., 2000) in addition to generating costs related to information asymmetry between central and divisional management. In a study of diversification in the US during the period 1986–91, Berger & Ofek (1995) found that diversification reduced the average value of the firm by 13–15%.[1] Langemeier and Rodney (2000) found that in relation to farm size and specialization in Kansas farms during the period 1982–2001, specialization increased the mean return of equity, but also increased the standard deviation of returns.

There are also arguments that diversification has a positive effect on firm value. Claims have been made that highly diversified firms have benefits relating to multiplant scale economies (Beckenstein, 1975), reduced incentive to forego positive net present value projects, larger debt capacity, lower taxes and benefits from managerial economies of scale and internal capital markets (Chandler, 1977). Further, one might argue that firms operating in markets where stability and predictability of supply are highly valued will be rewarded with a higher survival probability. When examining which firms choose to diversify, Pope and Prescott (1980) examined the connection between farm size and specialization. Using four measures of diversification, they found that larger firms are more diversified, and that wealthier and less experienced farmers are more specialized. This strengthens the claim that diversification comes at an economic cost but provides a higher survival rate for firms in the long run.

Davis et al. (2001) examined the assertion that increasing distance between a pair of peach orchards will reduce yield variability. By estimating a stochastic production function and decomposing variance into random and farm-specific effects, they found that correlations between orchards' yields decrease by 2.28% for every mile of distance between orchards.

It seems clear that the absolute economic effects on firm value when diversifying are strongly related to the characteristics of the specific industry. However, in general, diversification offers a method for the firm to reduce volatility of profits and secure the long-run stability of supply when production is stochastic because of local biophysical shocks.

Production Technology and Production Risk

Farmed salmon is produced in floating pens. Factors that influence output levels can be split between controllable and noncontrollable. The controllable inputs include smolt release into the pens, labor, feed, capital and materials. Among the most important decisions a firm makes is when and how many fish should be released into the pens and the amount of feed to give them (Guttormsen, 2008). In addition, firms make decisions concerning vaccination and treatment of diseases. The noncontrollable inputs include biological and climatic factors. Some of these factors are fish diseases, toxic algae, quality of fingerlings, water temperature and wind conditions. Together the controllable and noncontrollable inputs determine production levels and the quality of fish. Noncontrollable inputs are generally stochastic, that is, the farmers are not only unable to *influence* the levels of these inputs but also unable to *predict* these levels.

Production and price risk are inherent features of salmon farming (Vukina & Anderson, 1993; Gu & Anderson, 1995; Asche & Tveteras, 1999; Guttormsen, 1999; Tveteras, 1999; Kumbhakar, 2002; Oglend & Sikveland, 2008). Despite its impressive growth, the industry has experienced a high degree of turbulence and large cross-sectional variations in profitability. This has manifested as a large number of bankruptcies and restructuring of the industry. At the farm level, production risk has been an important factor, as many farms have experienced economic losses because of biophysical shocks such as fish disease outbreaks and extreme weather conditions. The high sensitivity of salmon to its environment, together with the rough weather conditions under which farms operate, probably means that there will be a relatively high permanent level of output risk compared with most other types of meat production.

Norwegian salmon farms are distributed along a long coastline with a variety of biophysical conditions. This applies particularly to sea temperature and water exchange, two important determinants of salmon growth and mortality. The average sea temperature is significantly lower in the northern counties than in the southern counties. The growth rate of salmon increases with sea temperature. On the other hand, because of tidal currents, the water exchange is higher in the northern regions than in the southern regions, implying that the supply of clean water and oxygen is higher in northern regions. Biophysical shocks, such as disease outbreaks and algae blooms, tend to be spatially correlated. When diseases occur, they will often lead to large losses at affected farms. Diseases are usually first transmitted to neighboring farms, and large-scale disease losses are often geographically confined to a limited part of the Norwegian coastline. This implies that if a salmon farming company has concentrated its production in a region hit by a disease outbreak, its production and profits may be severely affected.

The smallest unit that is regulated by the Norwegian government is a production *license*, and the total number of licenses is limited based on the government's environmental and economic considerations. In 2005, there were 922 salmon farming production licenses that had been awarded by the Norwegian government. For most counties, a license allows for a maximum allowable standing biomass (MASB) of live salmon of 780 tonnes. In the two northernmost counties, Troms and Finnmark, which represented 13% of total Norwegian production in 2006, the MASB is 900 tonnes per license. In 2006, the average national production per license was 960 tonnes, while for Troms and Finnmark it was 750 tons. This reflects the lower productivity in Troms and Finnmark because of temperature and light conditions.

Companies can merge several licenses together at a single plant (or farm). Farms are allowed to have from 1 to 6 licenses, depending on the biophysical capacity of the site. In other words, a farm site can have a MASB ranging from 780 tons (1 license) to 4,680 tons (6 licenses). Based on national average production in 2006, this means production ranging from 960 tons (1 license) to 5,760 tons (6 licenses) at one site.

Diversification in Salmon Farming

During the past 20 years, the industry has moved toward reducing the number of plants (or farms) and firms through mergers, which has lead to an increase in average plant and firm size. This has primarily been motivated by perceived economies of scale both at the firm and plant level. In the early 90s, there were 800–900 firms, but by 2004, the number of firms had decreased to less than 150 (Tveteras & Kvaløy, 2006). The consolidation is the result of the exploitation of economies of scale, high economic risk and imperfect capital markets that discriminate against small firms.

Previous research indicates that there are increasing returns to scale in the industry (Tveteras, 1999, 2002; Asche, Roll, & Tveteras, 2009), with a scale elasticity of about 1.2. With the general increase in average firm and plant sizes, scale economies are likely to have been exploited to a large degree. Furthermore, professional buyers' tendency to value stability of supply, and risk-averse financial investors' inclination to value reduced returns risk, should both reward diversification of production locations. In fact, we have observed that as the average size of Norwegian salmon firms has increased, the larger companies have also become geographically more diversified through ownership of farms in several regions and, for the largest companies, several countries.

Salmon farming is a single-output technology with a relatively homogeneous product. There has been little diversification in the product space, for example, into other fish species. Salmon farmers' diversification opportunities are primarily related to geographic localization of farms. For the decision makers, this is generally a trade-off between the mean and variance of profits and as such is affected by the firms' risk preferences.

Along the long Norwegian coastline, an additional important aspect of diversification is the cost of transportations and hence benefits of closeness to markets. As the main export market for Norwegian aquaculture is Europe, there exist clear economic benefits of localization in the south of Norway. However, as Russia is emerging as an important market, farms in the north will have a comparative advantage. In this sense, diversification of production in Norway will become more attractive as the Russian market grows, enabling a favorable trade-off in risk and returns as diversified farms serve different markets and provide a "storage" to smooth production shocks in local areas.

A Model for Diversification

In this section, we present our model for evaluating diversification. In the restricted case, this model will be equivalent to the standard Markowitz portfolio analysis (Markowitz, 1952, 1956).

To evaluate the effects of diversification, we will define each farm, identified by its regional location, as a value generating asset in which a given ratio of total available resources can be allocated. Assuming that the firm has a desired output level $\bar{y}$, the choice variable facing the firm is the geographical location of production units such that desired output is achieved and a given objective function is maximized. The objective function will be to minimize returns volatility given an expected returns level. Given n choices of location, a production share of $\alpha_i = \frac{y_i}{\bar{y}}$ for $i = [1, n]$ is located in region i such that $\sum_{i=1}^{n} \alpha_i = 1$. We denote the returns level when a share α_i of production is located in region i by $r_i(\alpha_i)$. We note that the returns generating function in the general case allows an increasing or decreasing returns scale if, for a given price level, $r_i'(\alpha_i) \neq 0$. The portfolio returns can then be stated as

$$r_p = \sum_{i=1}^{n} r_i(\alpha_i)\alpha_i \tag{1}$$

Further, the portfolio variance is given by

$$\mathrm{var}(r_p) = \sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_i \alpha_j \sigma_{ij} \tag{2}$$

Exploring the effect of the returns generating value on portfolio returns, we examine what happens to portfolio returns when a change in weights occurs. Differentiating equation (1) yields

$$dr_p = \sum_{i=1}^{n} r_i'(\alpha_i)\alpha_i d\alpha_i + r_i(\alpha_i)d\alpha_i \tag{3}$$

The first term in equation (3) gives the effect of changing weights on the returns generating function, linked to effects such as economies of scale or agglomeration. The last terms gives the effect of producing a higher output level in a region with a given returns level. Multiplying equation (3) by $r_i(\alpha_i)/r_i(\alpha_i)$ for all i gives the expression

$$dr_p = \sum_{i=1}^{n} r_i(\alpha_i)(1 + \varepsilon_i(\alpha_i))d\alpha_i \tag{4}$$

Here, $\varepsilon_i(\alpha_i)$ denotes the elasticity of returns and measures the percentage change in returns from changing weights in region i by one percent. Note that when a greater part of production is located in a region, the firm will gain a premium on doing so by $\varepsilon_i(\alpha_i)r_i(\alpha_i)$ if economies of scale benefits are present, that is $\varepsilon_i(\alpha_i) > 0$. However, under bounded resource constraints, increasing the weights in one location will necessarily reduce weights in at least one other region. Using the constraint $\sum_{i=1}^{n}\alpha_i = 1$, a specific weight might be expressed as $\alpha_k = 1 - \left(\sum_{l=1}^{k-1}\alpha_l + \sum_{m=k+1}^{n}\alpha_m\right)$. The portfolio returns are then given by

$$\begin{aligned} r_p = r_i(\alpha_i)\alpha_i &+ \sum_{k=1}^{i-1} r_k\left(1 - \left(\sum_{l=1}^{k-1}\alpha_l + \sum_{m=k+1}^{n}\alpha_m\right)\right)\left(1 - \left(\sum_{l=1}^{k-1}\alpha_l + \sum_{m=k+1}^{n}\alpha_m\right)\right) \\ &+ \sum_{p=i+1}^{n} r_p\left(1 - \left(\sum_{l=1}^{p-1}\alpha_l + \sum_{m=p+1}^{n}\alpha_m\right)\right)\left(1 - \left(\sum_{l=1}^{p-1}\alpha_l + \sum_{m=p+1}^{n}\alpha_m\right)\right) \end{aligned} \tag{5}$$

Differentiating equation (1) with respect to production share in location i and expressing as elasticities, we get

$$\frac{\delta r_p}{\delta \alpha_i} = r_i(\alpha_i)(1 + \varepsilon_i(\alpha_i)) - \sum_{k=1}^{i-1} r_k(\alpha_k)\left(1 + \frac{\varepsilon_k^i(\alpha_k)}{\alpha_i}\right) - \sum_{p=i+1}^{n} r_p(\alpha_p)\left(1 + \frac{\varepsilon_p^i(\alpha_p)}{\alpha_i}\right) \tag{6}$$

The elasticities ε_k^i and ε_p^i in equation (6) measure the substitution effect of changing weights in region i on alternative regions, that is, the scale effects of changing weights in alternative regions when weights are changed in region i. From equation (6), we observe how increasing the weight in one location will sacrifice eventual scale benefits in other locations. The optimal weight in each region must thus satisfy

$$r_i(\alpha_i)(1+\varepsilon_i(\alpha_i)) = \sum_{k=1}^{i-1} r_k(\alpha_k)\left(1+\frac{\varepsilon_k^i(\alpha_k)}{\alpha_i}\right) + \sum_{p=i+1}^{n} r_p(\alpha_p)\left(1+\frac{\varepsilon_p^i(\alpha_p)}{\alpha_i}\right) \quad (7)$$

The right-hand side illustrates the costs associated with diversifying in an industry with scale effects. When resource levels are bounded, focusing production in one region will sacrifice benefits in other regions. A further necessary condition for a non-corner solution, ignoring variance, is concave value generating functions, or in other words, economies of scale. That is, if risk-neutral firms choose to diversify, they will only do so if focusing all production in one region yields lower expected returns than spreading production.

The process of finding the portfolio with the highest expected returns for a given variance can equivalently be stated as finding the minimum variance of a given expected returns level. Hence, defining the objective function of the firm as the variance of returns, the general problem facing the firm can be stated as

$$\min_{\alpha_1,\ldots,\alpha_n} \sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_i\alpha_j\sigma_{ij} \quad (8)$$

such that

$$\sum_{i=1}^{n} \alpha_i = 1, \quad r_p = \sum_{i=1}^{n} r_i(\alpha_i)\alpha_i \quad (9)$$

In our case, we will impose one specific restriction on the problem. We assume that $r_i'(\alpha_i) = 0$ such that the elasticity of returns is zero, or in other words, no scale benefits are present. Note that this assumption also implies that the variance of the returns generating function is independent of the weights. This is arguably reasonable since factors such as disease outbreaks and local climatic changes, which are large contributors to major shifts in returns, are independent of the scale of production. The effects of relaxing these assumptions in the context of Norwegian aquaculture are discussed later. Imposing these restrictions makes our minimization problem solvable by an approximately linear optimization method.

Conditions for Diversification

In the linear diversification problem, the crucial parameter for successful diversification is the covariance between regional returns, that is, the term $\sigma_{ij}\,\forall i \neq j$. The lower the covariance $\forall i \neq j : \sum_{i=1}^{n}\sum_{j=1}^{n}\sigma_{ij}$, the better the trade-off between expected returns and returns risk. A major contributor to large fluctuations in returns is disease outbreaks. A disease outbreak implies that a specific farm location loses its entire stock of fish, as slaughtering of all stock is necessary. The economic consequences for the farm can naturally be grave.

Table 1 shows the correlations between regions in the share of farms hit by disease outbreaks from 1986 to 1998. As Table 1 shows, the correlations between outbreaks decrease as the distances between regions increase. The values closer to the diagonal indicate closer regions.

The table shows that, historically, the greater the distance between farms, the lower the probability of disease affecting the total stock of fish simultaneously. In other words, the disease outbreaks will influence a lower share of total production at smoother intervals, in effect reducing the impact of extreme value outcomes. Table 1 provides support for the argument that diversification will reduce production risk and increase the stability of supply.

What we are essentially interested in is the correlation between economic returns, the overall variance in which provides the most direct economic rationale for diversification. Table 2 suggests that returns correlations decrease for regions further apart. As a measure of the rate of returns, we use the operating margin from production. The operating margin measures the percentage of operating net income divided by sales. As with the disease statistics, the correlations between operating

TABLE 1 Correlations Between Disease Outbreaks Across Regions*

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	1									
P2	0.678	1								
P3	0.321	0.674	1							
P4	0.289	0.445	0.774	1						
P5	0.313	0.562	0.809	0.869	1					
P6	0.265	0.483	0.689	0.623	0.75	1				
P7	0.408	0.616	0.852	0.884	0.895	0.769	1			
P8	0.062	0.073	0.484	0.318	0.427	0.476	0.607	1		
P9	0.259	0.065	0.236	0.207	0.166	0.322	0.412	0.705	1	
P10	0.071	0.098	0.235	0.246	0.069	0.065	0.297	0.422	0.589	1

*The table shows correlations between disease outbreaks across Norwegian provinces calculated from the mean of yearly observations in the time period 1986–1998. Firms reported 1 if diseases occurred, 0 otherwise. P1–P10 are defined as the provinces from Rogaland in the south upward to Finnmark in the north.

TABLE 2 Correlations Between Operating Margins Across Regions*

	R1	R2	R3	R4	R5	R6	R7	R8	R9
R1	1								
R2	0.861	1							
R3	0.682	0.701	1						
R4	0.776	0.834	0.709	1					
R5	0.266	0.422	0.702	0.674	1				
R6	0.729	0.837	0.702	0.765	0.596	1			
R7	0.295	0.394	0.668	0.684	0.896	0.563	1		
R8	0.066	0.163	0.606	0.354	0.738	0.414	0.754	1	
R9	−0.301	−0.175	0.288	0.003	0.566	0.015	0.457	0.757	1

*The table shows the correlations between operating margins across regions calculated from 1985–1998. Note that because of lack of observations in Vest-Agder (F1) in the years 1985–1986, we have defined R1 to mean Rogaland and Vest-Agder, that is R1 = P1 + P2.

margins decrease as the distance between regions increases. Ignoring costs from diversifying, the effects of diversifying on returns risk indicate that conditions for diversification are present in the Norwegian aquaculture industry. For a firm heavily exposed in Rogaland and Hordaland, diversifying production to include Finnmark would reduce overall variance of operating margins.

For the risk-neutral producer, the desirable production location will only be motivated by expected operating margins and as such will be indifferent to correlations between margins. Since any short selling is unfeasible, the entire production will be focused in regions with the highest expected operating margin, or returns on investment. For a firm valuing stability in supply, however, eventually the correlations between margins will matter, and as such, the conditions seem present for improvements in stability by diversification. We now turn to portfolio analysis and evaluation of our optimization problem for the Norwegian aquaculture industry.

Model Evaluation

The following analysis will be based on an extensive panel data set consisting of 4,136 observations spanning the years 1985–2002. The data set is based on an annual questionnaire and is issued and compiled by the Norwegian Directorate of Fisheries. Because of the lack of reporting on locations after 1998, our analysis will be limited to the years 1985–1998.

Table 3 reports descriptive statistics on operating margins. We observe that, historically, Hordaland has had the highest average operating margins, with Møre and Romsdal coming in second. Predicting future returns based on these historical values suggests that a risk-neutral investor should focus all production in Hordaland. Further, the northernmost

TABLE 3 Descriptive Statistics for Operating Margins

	Observations	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
R1	343	9.603	23.716	−70.339	70.225	−0.520	3.906
R2	642	12.989	23.760	−87.776	87.584	−0.415	4.167
R3	381	12.750	26.281	−84.151	88.886	−0.408	4.224
R4	474	6.691	25.926	−74.015	84.143	−0.266	3.919
R5	278	6.863	27.508	−85.912	74.389	−0.806	4.372
R6	284	10.031	24.990	−89.397	68.100	−0.264	3.805
R7	580	10.069	23.618	−72.138	89.647	−0.306	4.623
R8	270	9.143	23.938	−87.344	62.955	−0.932	5.050
R9	81	7.540	32.286	−81.628	74.823	−0.766	3.456

*R1: Rogaland/Vest-Agder. R2: Hordaland. R3: Møre og Romsdal. R4: Sogn og Fjordane. R5: Sør-Trøndelag. R6: Nord-Trøndelag. R7: Nordland. R8: Troms. R9: Finnmark.

region, Finnmark, displays the highest standard deviation. Even though historical returns levels are relatively poor in Finnmark, the suggested negative correlation in operating margins would indicate attractiveness because of the possibility for risk reduction. The tendency for returns to be higher in the southern regions could be because of biophysical factors, agglomeration effects or closeness to market benefits (Tveteras, 2002; Tveteras & Battese, 2006).

Relative to the normal distribution, the operating margins in all regions display negative skewness and excess kurtosis. Negative skewness implies that the left tail of the distribution is longer, and the median is higher than the mean. This implies that the extreme negative outcomes are more common. Excess kurtosis, or a leptokurtic distribution, implies that the distribution has a higher peak and fatter tails than the normal distribution. This trait is often observed in economic time series, and it generates what is known as kurtosis risk. Kurtosis risk is linked to a higher than normal probability of extreme outcomes, while the negative skewness would locate most of this risk on negative outcomes. This is reasonable in an industry that, as stated, is sensitive to factors such as disease outbreaks and local climatic changes.

We now apply our model to our data set. Our solution generates portfolios of minimum variance or returns risk for a given expected returns level. This procedure will also return a vector of optimal investment weights for a given value on the minimum-variance curve. Figure 1 displays the points of minimum variance and shows where the specific regions are located relative to this curve. We observe how reduction in risk is made possible by diversifying production. The point on the curve closest to the vertical axis indicates the lowest possible variance attainable through diversifying. Increasing the mean returns from this point leads to a higher variance. The configuration necessary to achieve the minimum variance consists of producing approximately half the

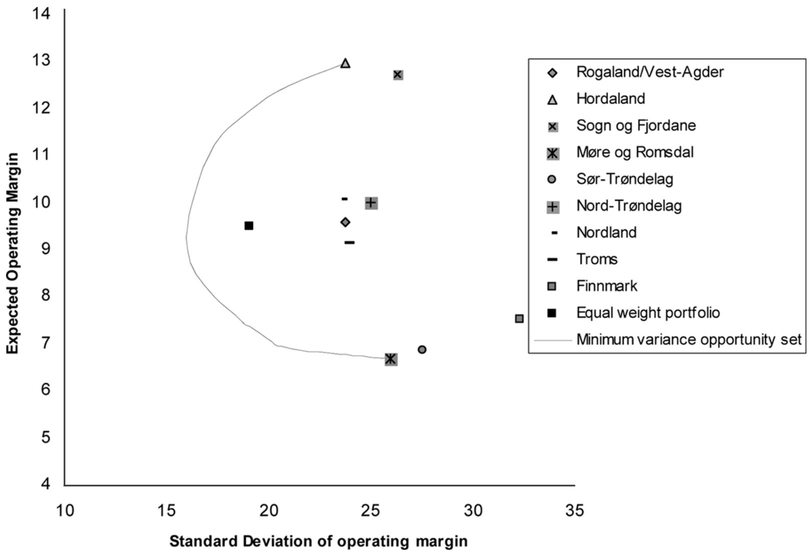

FIGURE 1 Points of minimum variance.

desired output in the southernmost region (Rogaland/Vest-Agder) and 30% in the northernmost region (Finnmark). The rest is divided between Hordaland and Nordland. In order to reduce risk, it is thus necessary to increase the distance between production facilities. Therefore, having an equal weight of production in each region, that is full diversification, will not optimally reduce risk. The fully diversified portfolio, however, will generate slightly higher expected returns than the minimum-variance portfolio, although with considerably lower risk reduction. Relative to mean returns and variance in Hordaland, the minimum-variance portfolio will reduce variance of returns by 32% at the cost of reducing expected returns by 29%.

We observe how the locations Rogaland/Vest-Agder, Nord-Trøndelag, Nordland and Troms seem to cluster between Hordaland and Møre og Romsdal. By moving to the northwest bounded by the curve, firms fully focused on these regions can, through diversification, both reduce risk and improve expected returns.

Note that no short selling is allowed in this portfolio analysis because of the infeasibility of such actions. If short selling was allowed, the points of optimality would not be bounded by the existing regions, and both expected returns and variance could be greatly improved because of the negative correlations present in the historical data.

The data analysis shows that because of the concavity of the minimum-variance curve, the cost in the form of giving up expected returns increases more rapidly as the diversification approaches the minimum-variance portfolio. In Figure 2, the top right is the historical average risk/returns for

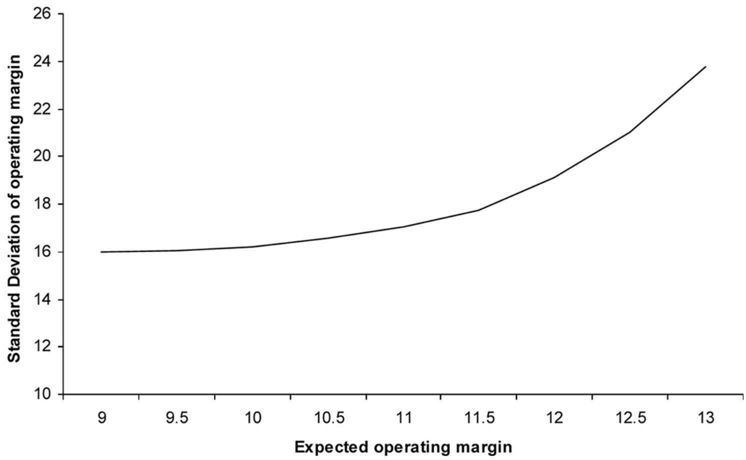

FIGURE 2 The expected return and risk–returns trade-off from diversification.

Hordaland. Moving down the curve, the benefits from sacrificing expected returns are relatively large. Reaching the minimum variance, however, incurs a considerable cost in the form of reduced expected returns. From this, the cost curve for diversifying, expressed as loss of expected returns, is a convex function. In the next section, we will discuss these results more closely in terms of Norwegian aquaculture and discuss how certain traits in the industry will affect the minimum-variance curve.

DISCUSSION

Which point on the minimum-variance curve a firm chooses will naturally depend on how much its owners value certainty and predictability. From Figure 2, the two extreme outcomes are, first, on the right, earning historically the maximum economic returns by locating solely at Hordaland, and secondly, on the left, ensuring the minimum variance of returns by diversification. Concerning economies of scale effects on diversification, we examine again the marginal effect on portfolio returns of changing the weight in one region:

$$\frac{\delta r_p}{\delta \alpha_i} = r_i(\alpha_i)(1+\varepsilon_i(\alpha_i)) - \sum_{k=1}^{i-1} r_k(\alpha_k)\left(1+\frac{\varepsilon_k^i(\alpha_k)}{\alpha_i}\right) - \sum_{p=i+1}^{n} r_p(\alpha_p)\left(1+\frac{\varepsilon_p^i(\alpha_p)}{\alpha_i}\right) \tag{10}$$

Economies of scale benefits are present if $\varepsilon_i'(\alpha_i) > 0\,\forall i$ assuming constant prices. As long as economies of scale are present, reducing the scale of production in a region will reduce the returns from that region by more than is implied by the linear weights. This indicates that our estimate

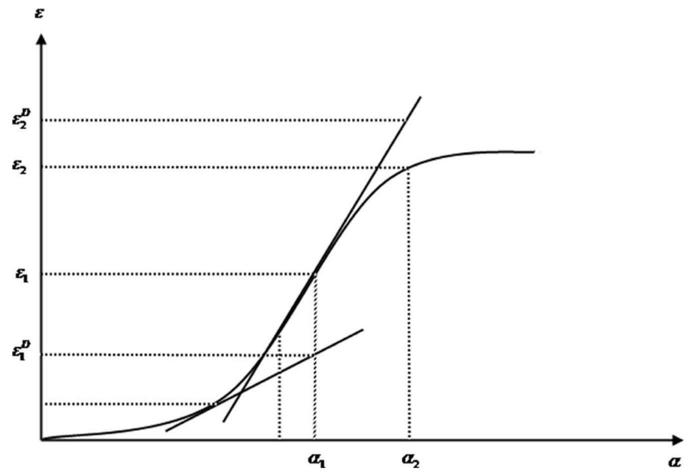

FIGURE 3 An illustration of the scale costs of diversification.

of the cost of diversifying is downward biased. However, recall that when diversification reduces scale in one region it will increase scale in others. If all production in province i is at the region of increasing returns to scale, illustrated in a hypothetical case in Figure 3 as the left of α_1, diversifying out of the region will come at a cost equal to $\varepsilon_1 - \varepsilon_1^D$. This illustration assumes the returns generating functions are equal across regions, which implies that equal weight diversification is optimal.

A full-scale production to the right of α_1, say at α_2, will cause diversification to come at a premium equal to $\varepsilon_2^D - \varepsilon_2$. As stated, Norwegian aquaculture seems to locate itself in the increasing returns to scale regions, so diversification will come at an extra cost. This effect will be magnified if the returns generating function is at a higher level in the region from which a producer is diversifying. This seems to be the case for some regions in Norway, such as in the south, where benefits such as closeness to markets can generate higher returns. However, in the case of the emerging market in Russia, the northern parts of Norway could observe an increase in returns, in effect closing the gap between north and south without necessarily increasing correlations in returns, making diversification more attractive. Further, as firms increase in size, we might observe an increasing in scale of operations as regional economies of scale are captured. This, however, will reduce the cost of diversification as the potential for further scale gains decreases relative to alternative regions.

We also note that the presence of economies of scale will change the risk effect of diversifying. Until now, we have ignored this. However, to examine what happens if we relax this assumption, consider the derivative of the portfolio variance with regard to the weight in location i:

$$\frac{\delta \operatorname{var}(r_p)}{\delta \alpha_i} = \left[\sum_{j=1}^{n} \alpha_j \sigma_{ij} + \alpha_i \alpha_j \frac{\delta \sigma_{ij}}{\delta r_i} \frac{\delta r_i}{\alpha_i} \right] \tag{11}$$

Note that under our assumption, $r_i' = 0$ such that changes in the variance move linearly with the weights. Tveteras (1999) showed that in Norwegian aquaculture, production risk is likely to increase with the scale of production. This implies that the second term in the above equation is positive. Again, the cumulative effect of increasing the weight in one region depends on the specific effects of scale of production on variance. If the effect of changing the value generating function on variance is constant and positive, existing in an area of increasing returns to scale will also increase aggregated variance when further increasing scale. For Norwegian aquaculture, this suggests that the risk reduction from diversification is potentially greater than that implied in the analysis above. It appears that in addition to reducing variance of returns from the reductions in correlations, diversification will also reduce variance through the effect of reducing scale.

For the Norwegian aquaculture industry, our analysis thus suggests that the potential for reducing the variance of returns is present, because of both reductions in correlations of returns and the effects of reducing scale. However, the existence of increasing returns to scale suggests that this diversification comes at a considerable cost. Because of a tendency for firm size to increase, this cost effect is believed to decrease if the current trend of market consolidation continues.

CONCLUSION

We examined the correlations in disease outbreaks and operating margins across regions and found that these correlations decrease as the distance between locations increase. In particular, there is a negative correlation in operating margins between the northernmost and southernmost parts of Norway. These correlations suggest that conditions for reducing risk through spatial diversification exist. Minimizing the variance of operational returns thus implies increasing the distance between production units, with a portfolio in which half of the desired output is from the southernmost region (Rogaland/Vest-Agder), 30% is from the northernmost region (Finnmark) and the rest is divided between Hordaland and Nordland. Since correlations decrease as the distances between regions increase, variance will not be minimized with equal weights in all regions, or full diversification. Relative to mean returns and variance in Hordaland (historically the region of maximum average operational returns), the minimum-variance portfolio will reduce variance of expected returns by 32% at the cost of reducing expected returns by 29%.

Historically, the average operational returns have been higher in the south, with a maximum in Hordaland. In addition, previous research has indicated that industry returns are increasing. Thus, diversification comes at an additional cost of reducing expected returns beyond the level assumed by a linear weighting scheme. However, as firm size increases and the scale benefits are captured, the cost of diversification will decrease as relative scale benefits across regions change. Increasing scale of production will increase the variance of output such that diversification will reduce variance not only through reduced sensitivity to local shocks to production, but also through the reduction in scale. In light of economies of scale, agglomeration and the increasing variance of production with scale, we believe the variance and costs estimates to be downward biased.

The difference in historical margins between the north and south can be reduced if the northern parts of Norway gain a comparative advantage linked to lower transportation costs to the Russian market. If the EU loses export shares relative to Russia, as has been the recent trend, this will provide an added incentive for spatial diversification in Norwegian aquaculture. Having an additional market not perfectly correlated with the main European markets will also reduce correlations in operating margins and provide an additional insurance from diversifying. As the share of salmon supplied to large retail chains by Norwegian aquaculture has increased, the demands on the industry for stability and predictability in supply have also increased. This has made diversification even more attractive.

Finally, it should be noted that for financial investors the opportunities to manage risk have increased as salmon companies' stocks are increasingly traded publicly. A financial investor thus can choose a desired expected return and risk by choosing an appropriate portfolio of stocks in salmon companies with different geographic locations.

NOTE

1. Berger & Ofek (1995) examined 3,659 firms from the US Compustat Industry Segment.

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