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Industrial Agglomeration and Production Costs in Norwegian Salmon Aquaculture

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Abstract *During the last decade, empirical evidence of regional agglomeration economies has emerged for some industries. This paper argues that externalities from agglomeration are not only present in some manufacturing and service sectors, but can also occur in primary industries, such as aquaculture. Econometric analyses in this literature have primarily estimated rather restrictive production function specifications on aggregated industry data. Here, cost functions are estimated on firm-level observations of Norwegian salmon aquaculture farms. This approach provides us with measures of the cost savings due to agglomeration externalities. Furthermore, we avoid aggregation biases and can test a rich set of hypotheses on how these externalities affect the structure of costs at the firm level. According to the econometric estimates, there are significant cost savings associated with localization in regions with a large salmon aquaculture industry, suggesting the presence of positive agglomeration externalities. In fact, the results here suggest that for small firms localized in clusters, agglomeration externalities can compensate for internal economies of scale, making them competitive relative to larger firms localized outside clusters. The econometric results imply that there are significant welfare gains to be made from changes in the government regulation of the industry.*

Key words Agglomeration, productivity, salmon aquaculture.

Introduction

The global salmon aquaculture industry is still in an early phase of its life cycle, but has already developed into a multi-billion dollar industry. The rapid growth of this industry has received considerable attention by policymakers, as they see a new source of jobs and tax revenue, but also a need to regulate due to environmental and other concerns. Shifts in the supply curve through productivity growth have been a driving force behind the industry's expansion (Asche 1997). At the same time, uneven economic performance across countries, regions, and firms led politicians, industry agents, and researchers to ask what are the determinants of productivity in this industry? Several earlier studies have shed some light on the structure of salmon production technology and costs.[1] This paper aims to provide some new insights into the importance of agglomeration economies for productivity and production costs in salmon farming.

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[1] See Salvanes (1989, 1993), Bjørndal and Salvanes (1995), Asche and Tveteras (1999), Tveteras, (1999, 2000), and Kumbhakar (2001).

Agglomeration economies are the economic benefits due to localization in a cluster. A cluster can be defined as a geographic concentration of inter-connected companies and supporting institutions, where firms receive economic benefits from localization in the cluster which are not obtained by firms residing outside the cluster (Porter 2000). From a static perspective, these economic benefits lead to increased productivity of firms. Increased capacity for innovation and sustained productivity growth are the main benefits in a more dynamic perspective. The sources of competitive advantage associated with localization in a cluster, the so-called agglomeration economies, are: (1) thicker input markets, (2) localized knowledge spillovers, and (3) complementarities due to better alignment of activities. These agglomeration economies will be discussed in more detail, both at a general level and for the specific industry of interest, salmon aquaculture.

The primary purpose of this paper is to measure the effects of regional agglomeration in salmon aquaculture on production costs. Are there any effects on unit costs, scale economies, and productivity growth? Agglomeration externalities act as cost shifters, and may not only shift the position of the unit cost curve, but also its slope. Production function based studies, which have dominated the empirical agglomeration literature, do not provide direct estimates of cost savings. Only two cost function approaches seem to have appeared in the literature, Henderson (1986) and Morrison Paul and Siegel (1999). Unlike the present paper, these two studies (and the production function approaches) employ aggregated data. In this paper, production models are estimated on firm-level data. Hence, the empirical results here should not suffer from the aggregation biases that are likely present in the empirical agglomeration literature.

One may ask if salmon aquaculture is an interesting case for a study of agglomeration economies. This is a highly relevant question, since conditions for agglomeration economies may not be present in all industries. Agglomeration will typically not occur when the level of technological sophistication is low, there is a limited degree of specialization, there is little indivisibility, and transportation costs are high. This was the case, for example, in traditional agriculture. Much of the cluster research has focused on manufacturing and IT services, where subsectors often are characterized by a high level of technological sophistication, specialization, and lumpiness. However, in several food production sectors, the nature of production and markets has changed so much that there should be (to an increasing degree) conditions for agglomeration economies.[2] For salmon aquaculture in particular, fundamental changes in the production process since the late 1970s should have led to increased possibilities for externalities due to agglomeration. It has moved from a labor-intensive production where workers had few formal skills, to a production which is more capital-intensive and where IT technologies have replaced several of the tasks of labor. Moreover, labor input has become more specialized; workers now tend to have certificates, and there is a much higher proportion of labor with a variety of specialized university educations.

The next section presents an overview of some central issues in the literature on industrial agglomeration. Following that is a discussion of salmon aquaculture, with emphasis on issues related to agglomeration externalities. Specification of the cost function that will be employed to test for agglomeration economies is next, followed by provision of the empirical results. Finally, conclusions are drawn.

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[2] Michael Porter (2000) uses the Californian wine industry as one example of a cluster.

Issues in the Agglomeration Literature

Since the late 1980s, there has been a renewed interest in externalities to firms' productivity arising from regional agglomeration of production. This has particularly been spurred by the contributions of Porter (1990) and Krugman (1991), representing two different directions in the research on industrial clusters. The Porter direction provides a rich, more informal explanation of mechanisms leading to competitive advantage, while the Krugman direction offers a more narrow, but also more precise, analysis of the sources of agglomeration economies. The *new economic geography*, which the Krugman direction has been termed, produced a number of theoretical and econometric analyses during the 1990s.

Traditionally, the study of the spatial location of factors of production has occupied a small part of standard economic analysis (Krugman 1991). Over time there has been a growing body of empirical evidence that the productivity of firms is influenced by several factors often ignored in conventional economic models. High transportation costs and indivisibilities can give rise to thin (or even non-existent) regional markets for specialized producer services and intermediate inputs, leading to higher input prices, inferior input quality, and suboptimal input choices. However, under these conditions, regional agglomeration of related production activities may give rise to *pecuniary externalities* through increased competition in input markets and provision of new specialized producer services and intermediate materials. The availability of specialized producer services allows firms to outsource some of their production activities to more productive external suppliers.

Agglomeration of related production activities may also lead to positive *technological externalities*. There is a growing recognition of the importance of physical proximity between agents in facilitating knowledge transmission and diffusion of innovations (Lundvall 1988; Saxenian 1990; Jaffe, Trajtenberg, and Henderson 1993; Audretsch and Feldman 1996; Baptista 2000, 2001). Increased availability of electronic communication technologies has not made face-to-face contact redundant. It is important to make a distinction between *information* and *knowledge* when assessing spatial transmission costs. The telecommunications revolution has dramatically reduced the marginal costs of transmitting information in geographic space, because information is easily codified and has a singular meaning and interpretation (*e.g.*, the price of gold on the New York Stock Exchange). Knowledge, on the other hand, is often tacit, complex, context specific, and uncertain. Hence, knowledge often has private goods characteristics and is costly to acquire. Factors influencing the likelihood of successful acquisition of knowledge or adoption of technology under these circumstances are physical observation and testing, duration and frequency of contact with the party possessing knowledge, degree of assistance or mentoring in initial application of knowledge or technology, and mutual trust between parties (Von Hipple 1994). When such factors are present, knowledge acquisition costs tend to increase with physical distance between parties.[3]

There are good explanations why localized knowledge diffusion processes and other sources of agglomeration economies have been ignored in economic models. First, their influences on firm productivity are much more difficult to observe and measure than the effects of conventional tangible inputs. Implementation in models is, therefore, difficult to defend empirically. Second, collection of data or anecdotal evidence on these intangible processes may involve costly and time-consuming field studies, an approach which is less used and has less prestige in the economics pro-

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[3] For a discussion of these issues, see Glaeser *et al.* (1992), Jaffe, Trajtenberg, and Henderson (1993), Glaeser (1999), and Baptista (2000, 2001).

fession than in other fields of research. Third, inclusion of agglomeration effects makes theoretical models more complex and analytically less tractable.

The literature has also proposed a linkage between the industry life cycle and the importance of physical proximity (Audretsch and Feldman 1996; Audretsch 1998). Industries which are highly innovative, where innovative activity tends to come from small firms, and where innovations tend not to be documented in the form of patents, are better characterized as being in the introductory stage of the life cycle. The later stages are characterized by lower innovation rates, where a high proportion of the innovative activity is undertaken in R&D departments of large firms. Salmon aquaculture is in the early stages of its life cycle. It was established in the late 1970s and has the characteristics typically associated with a young industry. It is argued in the literature that tacit knowledge should play a more central role in generating innovative activity during the early stages of the industry life cycle. From this, it follows that physical proximity is an important factor, as knowledge diffusion costs increase with distance.

The empirical literature in the new economic geography has been dominated by production function estimation on aggregated manufacturing data (Caballero and Lyons 1990, 1992; Bartelsman, Caballero, and Lyons 1994; Basu and Fernald 1995, 1997; Burnside 1996; Knarvik and Steen 1999). In its most general form, the production function is specified as $y = f(\mathbf{x}; E, t)$, where $\mathbf{x}$ is internal inputs, E is an external economy index, and t is a time trend variable representing exogenous technical change. The focus has been on externalities between industries, since the aggregated data have prohibited analysis of within-industry externalities. In some studies, the econometric estimates have provided indications of external economies between industries. However, the interpretation of these results has been questioned in a debate that includes several of the papers cited above.[4] Some of the most influential studies, for example, Caballero and Lyons (1990, 1992) and Basu and Fernald (1995, 1997), employed aggregated manufacturing data at the two-digit SIC level.[5] Unfortunately, it can be difficult to distinguish between internal and external economies of scale when such highly aggregated data are used. Production function approaches have also been restrictive in terms of the specification of input substitution possibilities and economies of scale, since the studies have used the overly restrictive Cobb-Douglas form. Moreover, it is not possible to uncover potentially interesting interactions between firm characteristics and externalities. Furthermore, studies have assumed homogeneous parameters for highly different industries, which seems unreasonable in light of empirical results that support industry-specific parameters (Burnside 1996). Another issue has been the choice of instrumental variables to correct for the probable correlation between productivity growth and input use, since input use might increase when firms take advantage of higher productivity levels, leading to correlation between the right-hand side variables and the error term. Burnside pointed out that regression results are highly sensitive to choice of instrumental variables, and that it is difficult to find appropriate instruments.

Morrison Paul and Siegel's (1999) (MPS) study represents a significant methodological departure from the previous studies of external effects. They estimate a variable cost function of the generalized Leontief form on two-digit level US manufacturing industry data. MPS use similar measures as Bartelsman, Caballero, and Lyons (1994) to capture customer- and supplier-driven externalities. Unlike the Cobb-Douglas based primal models, MPS's generalized Leontief specification allows for non-constant internal returns to scale, which is a source of bias in the previ-

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[4] See Burnside (1996) for a criticism of some of the cited studies.
[5] SIC: Standard Industrial Classification.

ously discussed studies. Moreover, variations in capacity utilization are explicitly captured by the quasi-fixed inputs, which represent the capacity for production. The shadow value of an external factor provides an indication of the cost savings from increasing the level of that external factor. Through interaction terms between external effects and input prices, the effects of externalities on input demands are accounted for. As MPS demonstrate, their model framework allows for identification of a number of effects of external factors that cannot be captured by the Cobb-Douglas production functions in earlier studies. MPS find cost savings and scale economy effects due to external factors. An advantage of the cost function approach compared to the production function approach in the studies cited above, is that instrumental variables are not required in a cost function approach to identify shocks. Exogenous changes and input demand responses are built into the cost function estimation model.

The empirical analysis in this paper employs a cost function approach on salmon aquaculture data. Unlike the production function-based studies and MPS's cost function study, a *firm level* data set is used. The use of disaggregated data allows one to test hypotheses on agglomeration externalities *within* an industry, rather than only on potential externalities *between* industries. There are *a priori* reasons to believe that the largest externalities between firms are within the same industry, since they have the most to learn from each other due to common production processes. Furthermore, firm-level data make it possible to compare firm *internal* economies of scale to *external* economies of scale, which is done here. Large external economies of scale relative to internal economies of scale have important implications for the competitiveness of small firms and industry structure. Several model specifications are estimated to accommodate for the different effects of pecuniary and technological agglomeration externalities. The specifications and motivation for these are presented in the econometric model specification section.

Norwegian Salmon Aquaculture: Technology and Organization

This section provides a description of the Norwegian salmon aquaculture industry with a focus on the possibilities for agglomeration externalities, particularly in the time period for which we have data on fish farms, 1985 to 1995.[6] During this data period, the industry was dominated by small-scale, owner-operated fish farms, despite a move towards increasing ownership concentration in the latter years of the period.

Salmon is farmed in open cages in seawater, usually in sheltered coastal areas.[7] The mode of production means that the industry faces substantial production risk (Tveteras 1999, 2000; Asche and Tveteras 1999). Since the salmon is directly exposed to an inflow of seawater from the marine environment, it is susceptible to fish diseases, toxic alga, and other harmful substances. Periodically, the industry has been subjected to large economic losses due to these external factors. Massive escape of fish from the cages due to extreme weather conditions and other factors has

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[6] In a research project funded by the Research Council of Norway, we conducted field studies that include interviews with a number of decisionmakers in the Norwegian aquaculture industry in order to uncover mechanisms that lead to agglomeration economies. This research provides a substantial body of anecdotal evidence on the presence of pecuniary and technological externalities in this particular industry, which is reflected in the discussion in this section.

[7] See Salvanes (1989, 1993) and Tveteras (1997) for a description of the production process in salmon farming.

also led to substantial losses. In its infancy, the industry suffered from insufficient knowledge about salmon biology and genetics, fish diseases, fish feed, and the functioning of the marine ecosystem. On-farm learning, together with public and private R&D, contributed to improving the understanding of important aspects of the production process, and led to a number of innovations. Until the early 1990s, the industry relied heavily on the use of antibiotics to combat diseases. Monitoring of the fish and production facilities was done manually. However, vaccine innovations that were introduced in the late 1980s and later years, reduced the dependence on antibiotics. Furthermore, increased use of IT-based, on-farm monitoring technologies and specialized producer services (*e.g.*, veterinarians, marine biologists, and fish laboratory facilities) has improved the surveillance of fish health and other biophysical parameters.

It can be argued that knowledge spillovers should be an important component of external economies in the salmon industry, and that such spillovers are localized. Although producers may have learned much from their own production experiences, they should have acquired valuable knowledge from others, since there are limits to the extent of own on-farm experimentation. In salmon aquaculture production, both management and workers have to make a large number of correct decisions and take the right actions at different stages in order to keep costs down, obtain a high product quality, and at the extreme, avoid adverse production outcomes which may lead to bankruptcy. A number of technologies and skills are involved in the different operations that are undertaken. Despite a generally increased understanding of central features of the production process and introduction of innovations, salmon farmers still face substantial uncertainty. On-farm experimentation and learning have always been important for improving productivity and have generated knowledge that often can be characterized as tacit and local, mainly because of the uncertainty and context specificity of the knowledge. The context specificity is due to the fact that the knowledge may be relevant only for the particular regime (*e.g.*, biophysical conditions at the farm location, stage of production process, genetic characteristics of the particular fish stock, and type of feed inputs), which was present when the knowledge was generated. Due to an incomplete understanding of the interactions in the fish culture environment, it has been difficult to isolate and measure the effects of biophysical shocks, new production practices, procedures, and technologies. Moreover, farmers have neither had the competence nor the incentives to provide a more formal written dissemination of knowledge that they have acquired. Salmon farmers located in the same region should have benefited most from knowledge generation through face-to-face contact in bilateral and multilateral settings. Local diffusion of knowledge may also have been facilitated by regional governments through their environmental and industry agencies.

Salmon producers may also learn from other agents in the industry infrastructure. Feed manufacturers, veterinarians, consultants, salmon fingerling producers, and researchers may be sources of knowledge on different aspects of the production process. Industry-specific infrastructure possessing knowledge or facilitating knowledge transmission is, to a large extent, organized in regional units or has a regional orientation. This is the case for local government agencies that monitor and assist fish farms on disease treatment, environmental issues (*e.g.*, farm location), and other matters that affect farm performance. The *Norwegian Fish Farmers' Association*, which is organized in regional units, is involved in training programs and dissemination of knowledge to fish farmers.

Another potential source of agglomeration economies is thicker markets for specialized inputs. Several types of capital equipment used by the salmon farming industry are characterized by lumpiness, where full capacity utilization requires that several farms demand their services.[8] The industry is also a heavy user of advanced computer-based technologies for different operations in the production process (Dietrichs 1995). Moreover, it demands specialized expertise in management, export marketing, installation, and maintenance of capital equipment, production monitoring, veterinary services, biology, *etc.* Provision of specialized producer services to the industry requires a certain minimum market size. Since the Norwegian industry is spread over a long coastline, with relatively high transportation costs for some factors of production, the relevant input market is generally the regional market. It can be asserted that an increase in the size of the regional salmon aquaculture industry will lead to the provision of more productive specialized physical and human capital inputs.

Although it has been argued here that both technological and pecuniary localized externalities may be present in salmon farming, it is possible that technological externalities dominate pecuniary externalities in terms of effect on production costs. This is because, as shown in table 1, salmon feed cost is the largest cost component, with a cost share of roughly 42% in our data set.[9] Salmon feed is produced by a small number of firms, and transportation costs are not very sensitive to transportation distances, which implies that the price of feed is not affected much by regional agglomeration. Inputs which are more likely to be affected by localized pecuniary externalities, such as materials and services, capital, harvest, freight, and smolt costs,[10] individually have much smaller cost shares. The potential for localized pecuniary externalities will vary between these inputs, and for capital (equipment) input in particular, the effect of agglomeration may be more indirect through substitution effects following changes in relative input prices.

There are several other reasons for using a regional division for the Norwegian salmon farming industry. First, regions have different 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, due to 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. Diseases are usually first transmitted to neighboring farms, and the probability of contagion is positively related to the density of farms. Density-dependent disease externalities can be regarded as a special type of congestion externalities. In this paper, we explore whether positive or negative density-dependent externalities dominate in salmon aquaculture. Historically, disease losses have not been evenly distributed along the Norwegian coast, but have been concentrated in certain regions. In our econometric production model, we use region-specific effects to account for differences in biophysical conditions.

Government regulations have played an important role in determining the spatial distribution of farms along the Norwegian coast. When salmon farming became economically viable in the early 1980s, a large number of entrepreneurs applied to the Norwegian government for licenses to establish farms. The central government

[8] Examples of lumpy capital inputs are vessels that transport salmon fingerling and salmon feed to the farms and live fish from the farms, slaughter facilities, equipment for handling and measuring fish, and devices for measuring biophysical parameters in the marine environment.

[9] When production costs include feed, capital, labor, materials and services, harvest, freight, and smolt costs, cf. table 1.

[10] Smolts are the salmon fingerlings that are reared in separate land-based facilities. These are sold to salmon farms when they are biologically ready for release into seawater.

Table 1
Summary Statistics for Salmon Firms

	Entire Sample		Regional Sample Mean Values[9]								
Variable	Mean	Std. Dev.	R	H	SF	MR	ST	NT	N	T	F
Feed cost[1]	3,294,220	2,356,001	2,901,422	4,094,342	3,410,319	3,732,338	3,088,293	2,569,785	3,050,092	2,669,322	2,483,579
Capital cost[1,2]	503,192	453,157	384,227	644,800	531,309	539,733	590,549	419,042	399,643	356,219	611,781
Labor cost[1]	919,340	570,209	784,826	1,015,315	942,080	997,117	1,023,771	828,555	862,539	788,408	837,077
Output[3]	276,985	238,695	244,471	345,099	295,288	294,863	254,764	213,979	260,124	241,407	218,589
Price feed[1,4]	9.77	4.60	9.10	9.84	9.44	10.24	10.62	9.99	9.48	9.14	10.19
Price labor[1]	128.89	51.71	133.82	141.51	140.83	137.82	119.81	109.18	120.63	116.64	110.41
Price capital[1,5]	0.20	0.17	0.19	0.20	0.20	0.20	0.21	0.20	0.19	0.19	0.17
Materials & services[6]	1,135,013	1,144,419	923,993	1,292,180	1,040,228	1,264,686	1,219,897	981,994	1,121,886	1,002,187	1,075,883
Harvest cost	375,108	743,701	371,944	400,824	249,696	348,350	351,180	268,979	480,220	508,961	285,406
Freight cost	64,605	154,369	44,337	49,353	16,385	86,339	51,275	58,776	120,881	58,575	45,809
Smolt cost	1,533,148	971,156	1,355,389	1,737,136	1,606,195	1,686,099	1,411,824	1,360,801	1,502,468	1,308,710	1,317,280
Reg. empl.[7]	752.22	297.52	342.99	1,151.51	553.30	868.28	558.14	399.27	937.11	574.07	569.33
Farm density[8]	0.0174	0.0115	0.0275	0.0352	0.0179	0.0196	0.0091	0.0127	0.0054	0.0041	0.0039
No. of obs.	2,638		218	507	308	389	234	244	458	202	77

[1] Costs and prices are measured in Norwegian kroner (NOK) and inflated to 1995 NOK by use of the consumer price index.
[2] Capital cost is defined as depreciation costs based on replacement value plus a user cost calculated as 7% of total capital.
[3] Output is measured as the fish harvest in kg, plus the change in stock of live fish in the pens during the year.
[4] The price of feed is observed in 1994–95. For the years 1985–93, the feed price has been constructed as the ratio of feed costs to the output.
[5] The price of capital is defined as the capital cost divided by total capital.
[6] Materials and services are measured by expenditures on maintenance and repairs, electricity, office equipment, rent of equipment and buildings, and other producer services and intermediate materials.
[7] Regional employment is measured in 1,000 man-hours, and includes all stages of salmon production (broodstock and roe, fry, smolts, and farmed fish).
[8] Farm density is measured as the number of farms per square km sea area.
[9] Regions: Rogaland (R), Hordaland (H), Sogn og Fjordane (SF), Møre og Romsdal (MR), Sør-Trøndelag (ST), Nord-Trøndelag (NT), Nordland (N), Troms (T) and Finnmark (F).

decided the number of licenses that should be awarded to each region, while regional/local authorities determined which entrepreneurs should obtain licenses and the location of farms in the region. License owners could not move the farm to another location or region, or sell the license without a permit from the authorities. It can be asserted that the government regulations produced a spatial farm distribution that would not have emerged with a national license auction system or free entry. It is natural to ask what effects regulation has had on the productivity of the industry. Are there welfare losses due to higher marginal production costs associated with the current spatial industry configuration?

Econometric Model Specifications

This section presents the empirical model specifications to be estimated. Furthermore, it provides a discussion of some important issues associated with the specification of the econometric models. Econometric studies of agglomeration effects generally include an agglomeration index with an observable proxy variable that is assumed to be highly correlated with the external economies. A primal model with agglomeration externalities can be written as $y = f(\mathbf{x}; E, t)$, where $\mathbf{x}$ is internal inputs, E is an external economy index, and t is a time trend variable representing exogenous technical change. Industry output or employment have often been used as agglomeration indexes in previous studies.[11] The dual long-run cost function to the production function $f(\cdot)$ is $C = C(\mathbf{w}, y, E, t)$, where $\mathbf{w}$ is a vector of factor prices. In the cost function framework, the agglomeration index, E, has an interpretation that is analogue to a quasi-fixed factor. The shadow-value of an external factor is $Z_E = -\partial C/\partial E$. It can also be expressed as an elasticity, $\varepsilon_E = -\partial \ln C/\partial \ln E$, where $\varepsilon_E < 0$ if there are cost savings associated with the factor.

In the empirical analysis, we examine the performance of salmon aquaculture producers in nine regions (see table 1). These regions are listed according to their location on the north-south axis, from the southernmost county of Rogaland (R) to the northernmost county of Finnmark (F). An unbalanced firm-level panel data set provided by the Norwegian Directorate of Fisheries is employed. This data set has 2,638 observations on 568 salmon aquaculture farms during the years 1985 to 1995. The farms are observed from one to eleven years. Information on the regional location of the farm, production level, input levels, costs, and revenues is included for each farm (cf. table 1 for summary statistics and variable definitions). In addition, data on total regional industry employment and the number of farms in the region were collected. These aggregate data allow construction of agglomeration indexes. As seen in table 1, there are substantial cross-regional differences in the size of the salmon aquaculture industry and the spatial concentration of production.

Two different measures are used here to represent agglomeration economies — total regional industry employment (denoted *RE*) and regional salmon farm density (*FD*). The agglomeration index can then be expressed as a function $E = E(RE, FD)$.

Total regional industry employment (*RE*) should capture external economies of scale. In particular, it can be viewed as a proxy for industry-specific human capital in the region, but it is probably also correlated with the specific physical capital of the regional industry. More innovations should be generated as the size of the re-

[11] For example, Caballero and Lyons (1992) use aggregate manufacturing output as agglomeration index E when analyzing data at the two-digit manufacturing sector level. Ciccone and Hall (1996) used a spatial density of employment index as the external effects index to explain differences in labor productivity across US states.

gional industry increases, and one would also expect that the infrastructure supporting diffusion of knowledge is upgraded as the industry becomes larger. According to table 1, there are substantial differences in the industry size across the nine regions, with the region of Rogaland at one extreme and Hordaland at the other extreme (employing on average 342 and 1,151 thousand man-hours, respectively, during the data period).

To account for density-dependent external effects among farms, the number of farms per square kilometer of sea area (*FD*) in the region is included. The proximity of farms can influence productivity in several respects. High farm density should enhance transmission of knowledge, particularly knowledge that requires some degree of physical observation and testing, as well as mentoring to be successfully acquired. It should also lead to a more efficient use of industry capital equipment, such as vessels for transportation of live fish and fish-processing facilities. Hence, investments by individual farms in capital equipment are expected to decline due to increased opportunities for sharing. This implies that there are external economies of scale associated with an increase in the number of farms in a region. On the other hand, there may be congestion externalities of a biological nature. Fish disease externalities among farms are expected to increase with higher farm density, leading to lower technical efficiency (and productivity).

A translog functional form is chosen for the econometric specification of the cost function. Region-specific fixed effects are implemented, thus allowing for shifts in the cost function for farms in different regions. These fixed effects represent biophysical factors, such as sea temperatures and currents, which have a large influence on productivity.

The long-run translog cost function with region-specific effects is specified as:

$$\begin{aligned} \ln C = {} & \Sigma_r \mu_r + \Sigma_i \alpha_i \ln w_i + 0.5 \Sigma_i \Sigma_j \alpha_{ij} \ln w_i \ln w_j + \alpha_y \ln y \\ & + 0.5\alpha_{yy} (\ln y)^2 + \Sigma_i \alpha_{iy} \ln w_i \ln y + \alpha_t t + 0.5 \alpha_{tt} t^2 \\ & + \Sigma_i \alpha_{it} \ln w_i \cdot t + \alpha_{yt} \ln y \cdot t + E(FD, RE\,; \beta) + u, \end{aligned} \tag{1}$$

where μ_r is a region-specific fixed effect, w_i is the price of input i (i = Feed, Labor, Capital), the time trend variable t is equal to one in 1985, u is a stochastic error term, and $E(FD, RE; \beta)$ is the agglomeration function.

The agglomeration function is specified as:

$$\begin{aligned} E(FD, RE; \beta) = {} & \beta_{FD} \ln FD + 0.5 \beta_{FD2} \ln FD^2 + \beta_{RE} \ln RE + 0.5 \beta_{RE2} \ln RE^2 \\ & + \beta_{FD \cdot RE} \ln FD \cdot \ln RE + \Sigma_i \beta_{FD,i} \ln FD \cdot \ln w_i + \Sigma_i \beta_{RE,i} \ln RE \cdot \ln w_i \\ & + \beta_{FD \cdot y} \ln FD \cdot \ln y + \beta_{RE \cdot y} \ln RE \cdot \ln y + \beta_{FD \cdot t} \ln FD \cdot t + \beta_{RE \cdot t} \ln RE \cdot t. \end{aligned} \tag{2}$$

This specification is flexible enough to allow testing of a number of hypotheses on the structure of agglomeration externalities. For example, to test if the marginal effect of agglomeration externalities on productivity is positive but decreasing ($\beta_{FD} > 0$ and $\beta_{FD2} < 0$; $\beta_{RE} > 0$ and $\beta_{RE2} < 0$), if agglomeration externalities are scale enhancing ($\beta_{FD \cdot y} \neq 0$; $\beta_{RE \cdot y} \neq 0$), if agglomeration externalities are input-biased ($\beta_{FD,i} \neq 0$; $\beta_{RE,i} \neq 0$, for some i), or if the size of agglomeration externalities has changed over time ($\beta_{FD \cdot t} \neq 0$; $\beta_{RE \cdot t} \neq 0$). These hypotheses will be discussed in more detail in the next section, where the empirical results are provided.

To improve the efficiency of the parameter estimates, the cost function is estimated together with the cost share equations $S_i = \partial \ln C / \partial \ln w_i$, using Zellner's seemingly unrelated regression technique (Zellner 1962).[12] Symmetry and homogeneity of degree one in factor prices are also imposed on the parameters. Input prices, output, and the agglomeration indexes were normalized to their sample mean values prior to estimation.

From the cost function one can derive returns to scale, which are defined as $\varepsilon_y = 1/(\partial \ln C/\partial \ln y)$. The conditional own price elasticity of demand for input i is defined as $\varepsilon_i = (\alpha_{ii} + S_i^2 - S_i)/S_i$ (i = Feed, Labor, Capital) (Binswanger 1974).

The cost elasticities with respect to regional farm density and regional industry size are:

$$\varepsilon_{FD} = \partial \ln C/\partial \ln FD = \beta_{FD} \ln FD + \beta_{FD2} \ln FD \\ + \beta_{FD \cdot RE} \ln RE + \Sigma_i \beta_{FD,i} \ln w_i + \beta_{FD \cdot y} \ln y + \beta_{FD \cdot t} t \tag{3}$$

$$\varepsilon_{RE} = \partial \ln C/\partial \ln RE = \beta_{RE} \ln RE + \beta_{RE2} \ln RE \\ + \beta_{FD \cdot RE} \ln FD + \Sigma_i \beta_{RE,i} \ln w_i + \beta_{RE \cdot y} \ln y + \beta_{RE \cdot t} t, \tag{4}$$

respectively. The null hypothesis is that both ε_{FD} and ε_{RE} have negative signs for the mean farm, implying that increased farm concentration and increased industry size lead to cost savings.

According to the discussion in the previous sections, there are two important sources of cost reductions associated with industrial agglomeration: (1) reductions in input prices through thicker markets for inputs (*i.e.*, pecuniary externalities) and (2) shifts in the production frontier through localized knowledge spillovers (*i.e.*, technological externalities). The latter effect is unproblematic in the context of the above cost model. It is captured by the parameters associated with the agglomeration indexes. The first effect is more problematic, since it implies that input prices, w_i, may be functions of the agglomeration indexes *FD* and *RE*. At the farm level, prices can still be regarded as exogenous, since there is a relatively large number of farms even in the smaller regions. But a causality between regional agglomeration and input prices can lead to high correlation between *FD* and *RE* and the input prices that we have observations on (feed, labor, and capital). The degree of correlation was examined, but found to be low for all input prices. Furthermore, regression of each of the input prices on agglomeration indexes and other variables that can influence input price formation suggest that a significant influence from agglomeration could only be found for the price of capital. However, the importance of the latter result should not be overestimated, since capital has the smallest cost share (cf. table 1).

Two different definitions of costs, C, were used in the estimation of the translog cost model. In the first model specification (denoted R1), feed, labor, and capital costs are included. Then, the estimated parameters associated with the agglomeration indexes *FD* and *RE* will only capture cost savings related to these three inputs. The ambition here is to estimate the effects of agglomeration on the total cost of production. To accommodate for this, one other model that includes more cost categories was estimated. In this model (R2), the costs associated with intermediate material and producer service purchases and smolt costs are added to the other costs. Hence, the second cost definition allows testing of a broader set of agglomeration externalities than the first definition. It should be noted that when only feed, labor,

[12] One of the share equations has to be deleted to obtain a nonsingular covariance matrix. The estimates are then asymptotically equivalent to maximum likelihood estimates and invariant to which equation is deleted (Barten 1969).

and capital are included in the cost function, it is implicitly assumed that these inputs are weakly separable from the other inputs used in the production process (Berndt and Christensen 1973). Salvanes (1989, 1993) and Bjørndal and Salvanes (1995) have argued for weak separability between these three inputs and smolt input in salmon farming. For materials and services input, one could argue that the separability condition is satisfied for some inputs.

Input prices are not observed for materials, services, and smolts. According to theory, these prices should be included in a long-run cost function when materials, services, and smolt costs are included in the dependent variable in model R2. Despite the potential biases associated with the absence of these input prices, it was decided to estimate models with materials, services, and smolt costs in the left-hand side variable, since there may be significant agglomeration effects to these cost categories. However, one should keep in mind possible omitted-variables biases when the estimation results from model R2 are assessed.[13]

One could argue that an alternative would be to estimate separate regression models for the cost categories where input prices are not observed to explain the influence of agglomeration effects. A cost model for, *e.g.*, material and service costs should include other variables which influence the level of these costs, such as prices of observed inputs, output, region-specific effects, and time-specific effects. However, agglomeration may not necessarily bring about a reduction in material and service costs for a farm. When agglomeration leads to improvements in the supply of intermediate materials and services, through reduced prices and/or higher quality, then these costs could (under some conditions) actually increase, as farms substitute away from other inputs, such as labor and capital. Hence, despite the lack of some input prices, it is useful to estimate a model that includes all costs, to capture the effects of agglomeration on all input decisions simultaneously.

Finally, a short-run cost function is estimated. Morrison Paul and Siegel (1999) point out that in the presence of input (quasi-)fixities there may be differences between short- and long-run agglomeration externalities. Salvanes (1993) found that input fixities were present in Norwegian salmon farming prior to the data period analyzed in this paper. To obtain a more complete picture of the structure of agglomeration externalities in the industry, a translog variable cost function with feed and labor as variable inputs and capital as fixed input is estimated:

$$\begin{aligned} \ln VC \; = \; & \Sigma_r\mu_r + \Sigma_i\alpha_i \ln w_i + 0.5\Sigma_i\Sigma_j\alpha_{ij} \ln w_i \ln w_j + \alpha_z \ln z + 0.5\alpha_{zz}(\ln z)^2 \qquad (5) \\ & + \alpha_y \ln y + 0.5\alpha_{yy}(\ln y)^2 + \Sigma_i\alpha_{iZ} \ln w_i \ln z + \Sigma_i\alpha_{iy} \ln w_i \ln y + \alpha_{zy} \ln z \ln y \\ & + \alpha_t t + 0.5\alpha_{tt}t^2 + \Sigma_i\alpha_{it} \ln w_i \cdot t + \alpha_{zt} \ln z \cdot t + \alpha_{yt} \ln y \cdot t + E(FD, RE\,;\beta) + u, \end{aligned}$$

where i = {Feed, Labor}, and z is physical capital measured in real NOK. Both a model with region-specific effects $\Sigma_r\mu_r$ (denoted SRR) and a model with firm-specific fixed effects $\Sigma_i\mu_i$ (denoted SRF) are estimated. The agglomeration function $E(FD, RE; \beta)$ is specified as in equation (2), except that the two terms involving the price of capital are replaced by the terms $\beta_{FD\cdot z}\ln FD\cdot\ln z + \beta_{RE\cdot z}\ln RE\cdot\ln z$. The variable cost function is estimated together with the cost share equation for fish feed using Zellner's SURE. Short- and long-run returns to scale are now $\varepsilon_{y\text{-}SR} = 1/(\partial\ln VC/\partial\ln y)$ and $\varepsilon_{y\text{-}LR} = (1 - \partial\ln VC/\partial\ln z)/(\partial lnVC/\partial\ln y)$, respectively (Caves, Christensen, and Swanson 1981). The short-run cost elasticity with respect to the agglomeration in-

[13] For example, technological progress embodied in materials, services, and smolt inputs should be captured by the time trend variable parameters. However, so could time trends in the unobserved prices of these inputs.

dexes *FD* and *RE* is found by taking logarithmic partial derivatives; *i.e.*, $\varepsilon_{FD} = \partial \ln VC/\partial \ln FD$ and $\varepsilon_{RE} = \partial \ln VC/\partial \ln RE$.

Empirical Results

This section discusses the empirical results from estimation of the translog cost model equation (1) – (2) on the sample of Norwegian salmon aquaculture firms.

Table 2 provides the estimated parameters from the translog cost models R1 and R2, and table 3 presents the associated elasticity estimates. More restricted specifications of the agglomeration function, equation (2), were tested for each of these models. For both models, likelihood ratio tests rejected models with no agglomeration effects (*i.e.*, all parameters associated with the agglomeration indexes FD and RD are equal to zero), only regional industry employment effects, and only regional farm density effects at the 99% confidence level. Hence, there is solid statistical support for the inclusion of agglomeration effects in the models.

The estimated region-specific fixed effects, which should capture permanent differences in biophysical conditions, translate into significant differences in production costs across regions for both models R1 and R2. Furthermore, in all models most of the terms associated with output level and factor prices are highly significant. According to the estimate of ε_{RTS} in table 3, there are increasing returns to scale for the mean farm in the sample. In model R1, which may be the most credible, the estimate of ε_{RTS} is 1.206. Model R2 has missing prices for some of the inputs, which may lead to an upward bias in the estimate of returns to scale. The own price elasticities of input demand are all negative across models for the mean farm, with feed input having the lowest elasticity, as expected. In model R1, the own price elasticities for feed, labor, and capital are –0.102, –0.205 and –0.256, respectively.[14] The calculated own price elasticities from model R2 are generally higher, and unreasonably high for capital, supporting the earlier conjecture of specification bias due to omitted input price variables. Most parameters associated with the time trend variable representing technical change are significant. The derived estimate of technical progress, *TC*, ranges from 2.4% in model R2 to 3.5% in model R1 for the mean farm. However, there is little evidence of scale bias or input biases in technical change.

Let us now turn to the parameters associated with the agglomeration effects, which are of primary interest in this paper. According to table 3, the elasticity of cost in regional industry size, ε_{RE}, is –17.5% in model R1 and –13.8% in model R2 for the sample average firm. Hence, both models suggest that there are fairly large cost savings associated with this agglomeration index. Later in this section, estimates of the savings in monetary terms will be presented. The predicted elasticity of cost in regional farm density, ε_{FD}, is somewhat smaller, but still indicates cost savings. For the sample average firm, the estimated elasticities from models R1 and R2 are –6.0% and –8.0%, respectively.

To show more clearly the economic significance of agglomeration externalities, it can be useful to plot the predicted unit costs from the estimated models. Unit costs are shown in figure 1 for different regional industry sizes, and in figure 2 for different regional farm densities. In both figures, we use sample average values for output, input prices, and other variables, and a range of values for the agglomeration indexes that correspond to the sample range.[15] We see that costs decline significantly

[14] For both the returns to scale and own price elasticities, the results from model R1 are similar to those in Salvanes (1989), who estimated long-run cost functions on Norwegian salmon data from earlier years (1982–83).

[15] The (min; max) values of regional industry size in the estimating sample are (190; 1,417) thousand man-hours, while the (min; max) values for regional farm density are (0.0018; 0.044) farms per square kilometer.

Table 2
Estimated Parameters of Translog Long-Run Cost Functions

	Model R1		Model R2	
Parameters	Coeff.	T-ratio	Coeff.	T-ratio
Region-specific fixed effects				
α_R	15.348	325.759	15.735	314.030
α_H	15.605	626.834	15.983	583.164
α_{SF}	15.449	653.518	15.832	609.276
α_{MR}	15.544	657.321	15.926	613.587
α_{ST}	15.455	486.601	15.832	465.053
α_{NT}	15.389	549.977	15.781	518.955
α_N	15.466	320.693	15.844	307.690
α_T	15.378	327.662	15.754	316.637
α_F	15.425	313.783	15.787	302.563
Output level and input price variables				
α_y	0.855	46.419	0.788	40.155
α_{y2}	0.071	7.528	0.087	8.823
α_{Feed}	0.659	128.401	0.443	88.174
α_{Labor}	0.214	58.710	0.142	56.609
$\alpha_{Capital}$	0.128	31.578	–0.004	–0.127
α_{FF}	0.145	42.627	0.178	50.919
α_{FL}	–0.102	–43.080	–0.034	–17.335
α_{FK}	–0.043	–17.793	0.008	1.921
α_{LL}	0.104	41.230	0.064	29.359
α_{LK}	–0.002	–0.989	–0.003	–1.405
α_{KK}	0.045	17.623	–0.015	–1.113
α_{yF}	0.090	31.489	0.083	30.076
α_{yL}	–0.066	–32.319	–0.029	–21.137
α_{yK}	–0.024	–10.681	–0.004	–0.288
Time trend variables and interaction with output and input prices				
α_t	0.052	7.452	0.066	8.776
α_{t2}	–0.014	–14.112	–0.015	–13.738
α_{yt}	0.000	0.064	–0.001	–0.533
α_{Ft}	0.009	12.365	0.002	2.311
α_{Lt}	–0.005	–9.621	–0.004	–11.995
α_{Kt}	–0.004	–7.018	–0.001	–0.218
Agglomeration variables and interaction with other variables				
β_{RE}	–0.173	–4.744	–0.151	–3.860
β_{RE2}	–0.019	–0.409	0.005	0.098
$\beta_{RE \cdot y}$	–0.014	–1.216	–0.014	–1.188
$\beta_{RE \cdot F}$	–0.004	–0.957	–0.008	–2.258
$\beta_{RE \cdot L}$	–0.006	–2.131	–0.005	–2.680
$\beta_{RE \cdot K}$	0.009	3.144	0.007	0.383
$\beta_{RE \cdot t}$	–0.003	–0.992	–0.001	–0.323
β_{FD}	–0.051	–1.437	–0.063	–1.699
β_{FD2}	0.058	2.007	0.053	1.774
$\beta_{FD \cdot y}$	0.011	1.860	0.016	2.505
$\beta_{FD \cdot F}$	0.016	7.423	0.018	8.724
$\beta_{FD \cdot L}$	–0.015	–10.277	–0.006	–5.815
$\beta_{FD \cdot K}$	0.000	–0.166	0.010	0.960
$\beta_{FD \cdot t}$	0.001	0.595	0.000	–0.106
$\beta_{RE \cdot FD}$	–0.038	–1.204	–0.057	–1.689
Log-likelihood	9,470.13		9,935.13	
R-squared	0.9998		0.9998	

Table 3
Elasticity Estimates from Long-Run Cost Functions

	Model R1		Model R2	
Elasticity	Mean	St. Err.	Mean	St. Err.
ε_y	1.206	0.076	1.349	0.116
ε_{Feed}	–0.102	0.068	–0.122	0.091
ε_{Labor}	–0.205	0.295	–0.267	0.378
$\varepsilon_{Capital}$	–0.256	1.009	–1.311	0.678
TC	–0.035	0.045	–0.024	0.047
ε_{RE}	–0.175	0.040	–0.138	0.049
ε_{FD}	–0.060	0.046	–0.080	0.046

Note: Elasticities are evaluated at the sample mean level of the regressors.

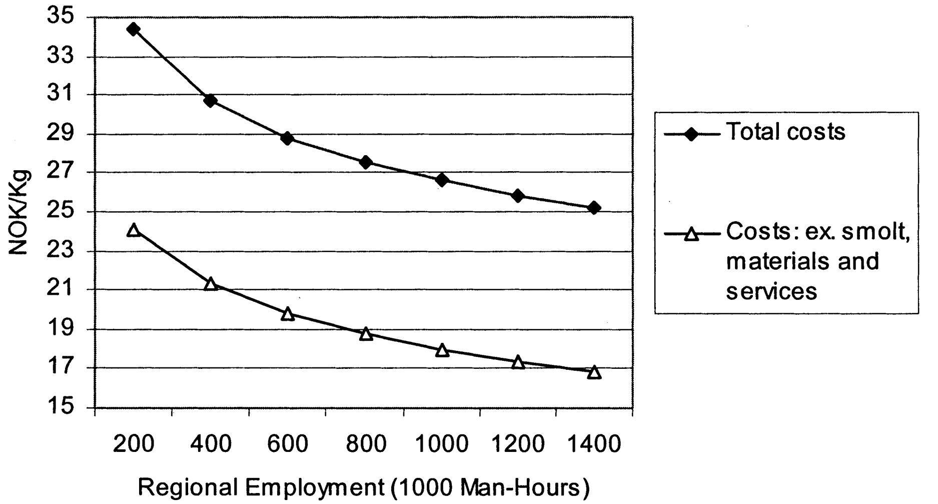

Figure 1. Estimated Unit Production Costs for Different Regional Industry Sizes from Models R1 and R2

in regional industry size for both cost definitions. The effect of regional farm density is much weaker, and benefits from physical proximity seem to be exhausted at high farm densities.

As stated in the introduction, it has been put forward in the literature that physical proximity is more important in earlier stages of the industry's life cycle than in later stages, since tacit knowledge should play a more central role. One can argue that there may have been important changes in the knowledge diffusion processes during the data period 1985–95, as the salmon industry and surrounding institutions evolved, leading to less reliance on tacit knowledge and physical proximity. This should be reflected in the parameters associated with the interaction terms between the agglomeration indexes and the time trend variable, the $\beta_{FD\cdot t}$ and $\beta_{RE\cdot t}$ parameters. However, the estimates of these parameters are not significantly different from zero

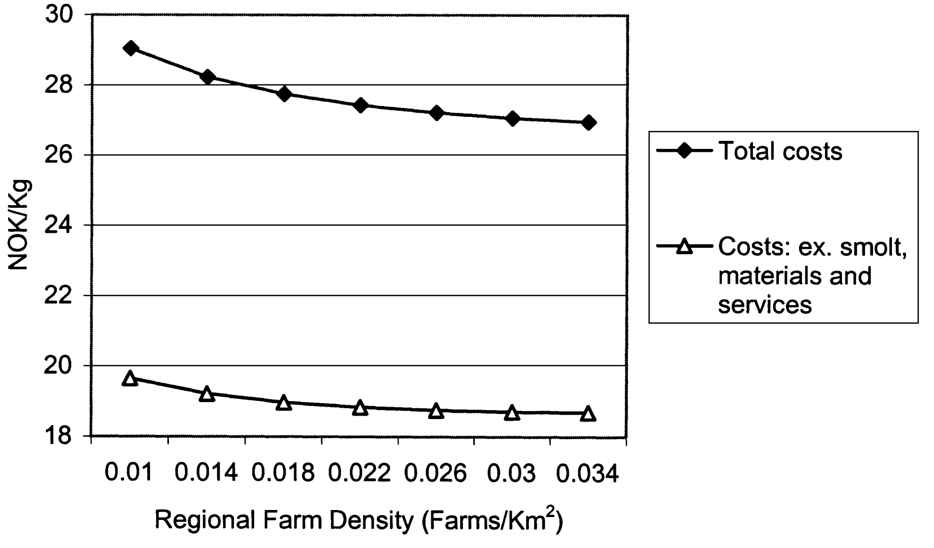

Figure 2. Estimated Unit Production Costs for Different Regional Farm Density Levels from Models R1 and R2

in any of the models reported in table 2. Furthermore, an examination of the individual components of the estimated elasticities, ε_{FD} and ε_{RE}, cf. equations (3) and (4), reveals that the term involving the time trend variable has relatively little influence on the elasticity estimate for both ε_{FD} and ε_{RE}.[16] Overall, these results suggest that the size of agglomeration effects on costs has not changed much over time.

The 'neutral' component of the elasticities ε_{FD} and ε_{RE}; *i.e.*, the first two right-hand terms of the expressions (3) and (4), is the dominant factor explaining the elasticity estimates for both regional industry size and farm density. The 'internal scale' parameter, $\beta_{RE \cdot Y}$, is statistically insignificant in all models, indicating that industrial agglomeration, as measured by the index *RE*, benefits neither small firms nor large firms in particular. However, the parameter $\beta_{FD \cdot Y}$ is positive and statistically significant in all models, indicating that large firms seem to benefit less from agglomeration as measured by farm density. The explanation for this may be that large farms are more vulnerable to density-dependent fish diseases, as they have larger quantities of fish in the cages. Industrial agglomeration seems to have little effect on the cost shares of inputs, according to the interaction terms between input prices and agglomeration indexes ($\beta_{RE \cdot F}$, $\beta_{RE \cdot L}$, $\beta_{RE \cdot K}$, $\beta_{FD \cdot F}$, $\beta_{FD \cdot L}$, $\beta_{FD \cdot K}$).

It is of great interest to examine the relative strength of internal returns to scale and external agglomeration effects on production costs. Figure 3 plots predicted costs from model R1 for different internal output levels, and for three different regional industry sizes. We see that unit costs decline significantly as production is increased. However, the estimated influence of external economies is such that a small firm in a region with average industry size (RE ≈ 752 thousand man-hours) has lower production costs than a larger firm in a small region in terms of industry size

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[16] The estimated contributions of the individual terms of equations (5) and (6) to elasticity estimates ε_{FD} and ε_{RE} are not reported in table 3. However, the estimates of parameters associated with cross-terms between agglomeration variables and other variables in table 2 indirectly provide information on their contribution.

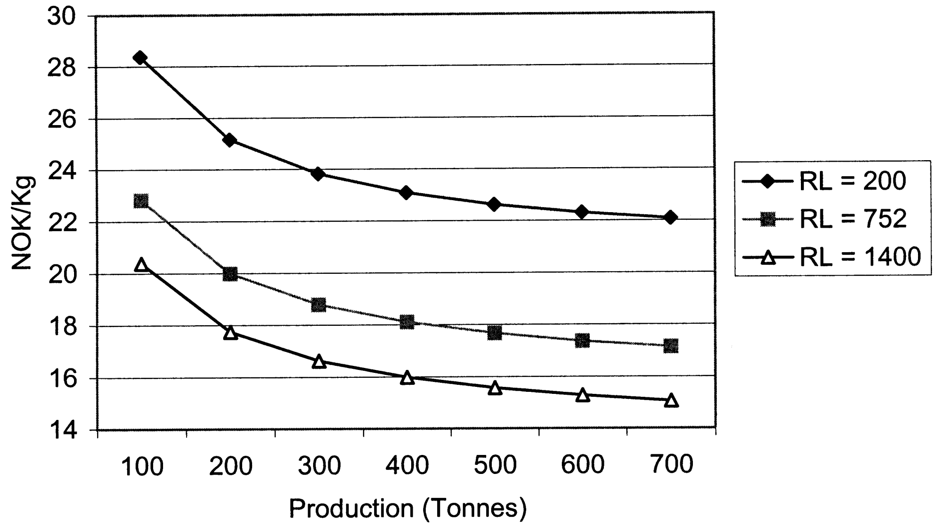

Figure 3. Estimated Unit Production Costs for Different Firm Output Levels and Regional Industry Sizes from Model R1

(RE ≈ 200 thousand man-hours). It seems, however, that the advantage from regional agglomeration becomes less important relative to internal scale economies when regional employment is larger than average. This is consistent with the plot of model R1 in figure 1, where we see that costs decline more steeply for low regional industry size levels. This may indicate that the gains from thicker markets and knowledge spillovers are larger when the regional industry grows from a smaller base.

Next, we examine the empirical results from the short-run variable cost function, as specified in equation (5). Table 4 reports the parameter estimates from the model, and table 5 provides the derived elasticity estimates. Support for the short-run specification is provided both by a likelihood ratio test and most of the t-ratios of individual parameters associated with the quasi-fixed capital input. The estimate of long-run returns to scale (ε_{y-LR}) is 1.142, somewhat lower than the estimate from the long-run translog cost function R1.

What are the predictions from the estimated short-run cost function on agglomeration economies? The mean short-run elasticity of variable costs with respect to regional industry size (*RE*) is –19.1%. Hence, there are substantial short-run cost savings associated with increasing regional industry size, even when we include only feed and labor in the cost definition. This could indicate that technological externalities dominate over pecuniary externalities, since we believe that pecuniary externalities associated with feed and labor are small. For regional farm density we also find cost savings in the short run, but these are small, with a mean short-run elasticity of –2.9%.

Overall, the empirical results here support the earlier assertion that localized technological externalities dominate pecuniary externalities. The basis for this is a comparison of the calculated agglomeration elasticities in long-run cost function R1 and short-run cost function with the long-run cost function R2. The two former specifications include cost components in the left-hand side variable which *a priori* are believed not to be influenced much by localized pecuniary externalities, while

Table 4
Estimated Parameters of Translog Short-Run Cost Function

Parameters	Coeff.	T-ratio
Output level, input prices, and quasi-fixed input variables		
α_y	0.881	46.480
α_{y2}	0.096	9.460
α_{Feed}	0.772	188.020
α_{Labor}	0.228	55.400
α_{FF}	0.125	48.910
α_{FL}	–0.125	–48.910
α_{LL}	0.125	48.910
α_z	0.015	1.310
α_{z2}	0.015	2.860
α_{FZ}	–0.033	–18.860
α_{LZ}	0.033	18.860
α_{yF}	0.105	41.510
α_{yL}	–0.105	–41.510
α_{yz}	–0.041	–6.950
Time trend variables and interaction with output, input prices, and quasi-fixed input		
α_t	0.043	6.500
α_{t2}	–0.011	–11.310
α_{yt}	–0.005	–2.130
α_{Ft}	0.003	5.320
α_{Lt}	–0.003	–5.320
α_{zt}	0.006	3.860
Agglomeration variables and interaction with other variables		
β_{RE}	–0.185	–5.570
β_{RE2}	–0.023	–0.560
$\beta_{RE \cdot y}$	–0.012	–1.110
$\beta_{RE \cdot F}$	0.007	2.340
$\beta_{RE \cdot L}$	–0.007	–2.340
$\beta_{RE \cdot z}$	0.015	1.880
$\beta_{RE \cdot t}$	–0.003	–0.970
β_{FD}	–0.021	–0.640
β_{FD2}	0.033	1.270
$\beta_{FD \cdot y}$	0.016	2.680
$\beta_{FD \cdot F}$	0.019	11.610
$\beta_{FD \cdot L}$	–0.019	–11.610
$\beta_{FD \cdot z}$	–0.004	–0.940
$\beta_{FD \cdot t}$	0.000	0.140
$\beta_{RE \cdot FD}$	–0.030	–1.060
Log-likelihood	5,537.18	
No. of obs.	2,638	

Note: Region-specific intercepts are not reported due to space considerations.

Table 5
Elasticity Estimates from Translog Short-Run Cost Function

Elasticity	Mean	St. Err.
ε_{y-LR}	1.142	0.063
$\varepsilon_{Feed-SR}$	–0.072	0.061
$\varepsilon_{Labor-SR}$	–0.266	2.991
TC_{SR}	–0.025	0.038
ε_{RE-SR}	–0.191	0.035
ε_{FD-SR}	–0.029	0.029

Note: Elasticities are evaluated at the sample mean level of the regressors.

the latter specification includes inputs (*e.g.*, materials and services) for which prices are believed to be influenced by pecuniary externalities. Nevertheless, the estimates of the elasticity ε_{RE} are larger in the two former models than in the latter, while the opposite should have been the case if pecuniary externalities associated with *e.g.*, materials and services were present. For the farm density elasticity ε_{FD}, the difference in estimates between models R1 and R2 is small.

Summary and Conclusions

This paper has investigated the possibility of production cost savings associated with regional agglomeration of salmon aquaculture production. It is argued here that the salmon industry has several characteristics giving rise to agglomeration economies. Increased concentration of salmon production can provide benefits in the form of thicker input markets, increased localized knowledge spillovers, and complementarities due to better alignment of production activities.

Both long- and short-run flexible cost functions were estimated on firm-level data. Thus, potential aggregation biases that may be associated with earlier studies are avoided, and it is possible to test effects of agglomeration on firms' costs, scale economies, and input demands. Estimation of several specifications is necessary in order to allow testing of different hypotheses on the structure of agglomeration economies in Norwegian salmon aquaculture. Use of a short-run specification is supported by the empirical results. However, a variable cost function only allows direct testing of the cost effects of agglomeration externalities on a subset of inputs in salmon farming. Hence, while recognizing potential biases, long-run specifications that includ a wider range of inputs were estimated in order to obtain estimates of the full effects of agglomeration on production costs. The empirical results from cost models that allow separation of internal and external influences on production costs provide support for the presence of agglomeration economies that lead to cost savings in salmon farm production. These results seem to be robust to changes in econometric model specifications. Cost savings are found to be associated with both increasing regional industry size and regional farm density. However, the positive externalities seem to be stronger in regional industry size than in farm density. According to the results here, the external economies are also significant compared to the estimated internal scale economies. Under some circumstances, the estimated models predict that smaller firms in regions with a large industry have lower production costs than larger firms located in smaller regions.

The results suggest indirectly that technological externalities dominate over pecuniary externalities. This is because the model specifications that include only inputs in the left-hand side cost variable, which are believed not to be subject to pecuniary externalities, provide high agglomeration elasticity estimates compared to the specification that also includes inputs believed to be subject to pecuniary externalities.

The results in this paper have implications for welfare and public regulations. Through its regulations, the Norwegian government has influenced both the total industry size and the regional distribution of salmon producers. By allowing the size of the Norwegian industry to increase through provision of new salmon production licenses, the government can contribute to reducing the marginal costs of production due to increased agglomeration externalities. A relaxation of restrictions on the regional location of farms could lead to a spatial reallocation of farms, where regions that are able to attract new farms could experience increased positive externalities to productivity. However, this could also lead to lower productivity for regions that lose farms. One should also be aware, as the results here provide indirect support for, that higher farm densities can lead to negative externalities due to fish diseases, which could dominate the positive agglomeration externalities from physical proximity.

There exist several potential barriers to regional cluster expansion besides government regulations. One such barrier is competition with other user interests. Some regions are endowed with institutions, suppliers, and related industries that have capacity to support a larger salmon aquaculture industry than is present today. However, in these regions other user interests often provide serious opposition to use of productive sites, and are able to prevent or delay establishment of new production capacity. Of course, an alternative to establishing new farms is to allow increased production at existing sites with unused capacity. Another challenge is availability of qualified labor in local labor markets. The skill-biased technological change in the salmon industry has led to an increasing demand for workers with higher education. Unfortunately, highly educated people tend to prefer living in more urban areas with a greater supply of shopping opportunities and cultural amenities, whereas productive farm sites tend to be in more remote areas. Access to infrastructure, such as roads, electricity, and telecommunications, is arguably a smaller problem in Norway than in competing countries.

This study has focused on cost savings from agglomeration until 1995. There are, however, several developments with relevance for agglomeration economies that have mainly taken place after 1995. One such trend is the emergence of large, multinational corporations with integrated salmon production and distribution operations. These corporations may, in addition to owning a large number of salmon farms in several countries, also own salmon feed production capacity, smolt production capacity, fish processing capacity, and export companies. Their headquarters and R&D facilities are typically localized close to larger cities with strong supporting institutions and an international airport. The specialized expertise employed by the corporations tends to be located in or near the headquarters, and to a lesser extent, in the regions. Since these corporations often are self-sufficient in many areas and are not embedded in the regions where they have production capacity, they will, to a smaller extent, contribute to development of regional markets for specialized inputs and dissemination of knowledge. This means that the level of positive externalities from agglomeration may decline when a large corporation acquires ownership interests in a region where it has not localized its headquarters. The large corporations may, however, contribute to agglomeration economies at a higher level, such as the national level. Most of the emerging corporations with multinational operations have Norwegian ownership, and tend to locate their headquarters and specialized functions, such as R&D departments, in Norway. This physical proximity means that the flow of services from highly productive inputs and innovating milieus will tend to benefit the Norwegian industry more than the industry in Chile and Scotland, the two main competitors, thus leading to a competitive advantage for

Norway. On the other hand, these advantages may be offset by higher spatial concentrations of salmon farms in parts of Chile and Scotland, if similar localized agglomeration economies, as found in this paper, are at work in these countries.

Agglomeration externalities between salmon aquaculture and related industries have not been investigated here. Salmon farming has dominated the Norwegian aquaculture sector so far, but aquaculture of other species is now emerging due to technological breakthroughs, declining supply of competing wild species, and increased market demand. There should be important linkages between salmon and other species, both in production and marketing, due to similarities in production technology and sharing of specialized inputs. Increased production of other species could lead to the realization of agglomeration economies in regions which have yet not benefited from these, because they were constrained by production capacity regulations in salmon farming.

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