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Effects of Regional Agglomeration of Salmon Aquaculture on Production Costs

by

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Abstract

During the last decade empirical evidence of regional agglomeration economies has emerged for some industries. This report 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 production functions 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 richer set of hypotheses on how these externalities affect the structure of costs. 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. The econometric results imply that there are significant welfare gains to be made from changes in the government regulation of the industry.

1. 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 caused considerable interest by policy makers, seeing 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 has been a driving force behind the industry expansion (Asche, 1997). But at the same time uneven economic performance across countries, regions and firms has lead both 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 report aims to provide some new insights on the importance of agglomeration economies for productivity and production costs in salmon farming.

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 have economic benefits from localization in the cluster which are not obtained by firms residing outside the cluster (Porter, 2000). In 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 report 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 seemed to have appeared in the literature, Henderson (1986) and Paul and Siegel (1999). But unlike the present report, these two studies (and the production function approaches) employ aggregated data. In this report

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

production models are estimated on firm level data. Hence, the empirical results here should not suffer from the aggregation biases that probably are 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 are few indivisibilities, 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 sub-sectors often can be characterized by a high level of technological sophistication, specialization and lumpiness. But also in several food production sectors the nature of production and markets has changed so much that there to an increasing degree should be conditions for agglomeration economies.[2] For salmon aquaculture in particular, fundamental changes in the production process since the late 1970s should have lead to increased possibilities for externalities due to agglomeration. One 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 we find a much higher proportion of labor with different types of specialized university education.

Section two presents an overview of some central issues in the literature on industrial agglomeration. Section three provides a discussion of salmon aquaculture, with emphasis on issues related to agglomeration externalities. Section four presents the specification of the cost function that will be employed to test for agglomeration economies. In section five the empirical results are provided. Finally, conclusions are drawn in section six.

2. 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

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

offers more narrow but also a 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). But over time one has seen 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.

Furthermore, 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, 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 is 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

[3] For a discussion of these issues, see Glaeser, Kallal, Scheinkman, and Shleifer (1991), Jaffe, Trajtenberg and Henderson (1993), Glaeser (1999), and Baptista (2000, 2001).

processes may involve costly and time-consuming field studies, an approach which is less used and has less prestige in the economics profession than in other fields of research. Third, inclusion of agglomeration effects make 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 is characterized by lower innovation rates, where a high proportion of the innovative activity being 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 (e.g. Caballero and Lyons, 1990, 1992; Bartelsman, Caballero and Lyons, 1994; Basu and Fernald, 1995, 1997; Burnside, 1996; Knarvik and Steen, 1999). These studies have tried to separate the effects of internal inputs and externalities on aggregate industry productivity. Unfortunately, it can be difficult to distinguish between internal and external economies of scale when aggregated data are use.[4]

3. 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 that we have data on fish farms, 1985 to 1995.[5] During this data period the industry was

[4] See Burnside (1996) for a criticism of some of the cited studies.

[5] We have conducted field studies that included interviews with a number of decision makers 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.

dominated by small-scale owner-operated fish farms, despite a move towards increasing ownership concentration in the latter years of the data period.

Salmon is farmed in open cages in sea water, usually in sheltered coastal areas.[6] 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 sea water from the marine environment it is susceptible to fish diseases, toxic algaes 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 have also lead 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 lead to a number of innovations. Until the early 1990s the industry relied heavily on use of antibiotics to combat diseases. Monitoring of the fish and production facilities were 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. 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 right decisions and actions at different stages in order to keep costs down, obtain a high product quality, and at the extreme, avoid catastrophic outcomes. 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 the productivity, and has generated knowledge that often can be characterized as tacit and localized, mainly because of the uncertainty and context specificity of the knowledge. The context specificity is due to the fact that the knowledge may be

[6] See Salvanes (1989; 1993) and Tveterås (1997) for a description of the production process in salmon farming.

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 have 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.[7] 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, 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 high transportation costs for 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

[7] 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.

salmon aquaculture industry will lead to the provision of more productive specialized physical and human capital inputs.

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 report, 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 were 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 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?

4. Econometric Model Specifications

This section presents the empirical model specifications to be estimated and 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 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.[8] 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 are 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 allows construction of agglomeration indexes. There are substantial cross-regional differences in the size of the salmon aquaculture industry and the spatial concentration of production according to Table 1.

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 regional industry increases, and one could also expect that the infrastructure supporting diffusion of knowledge is upgraded as the

[8] 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.

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 1151 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, and 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. Two sets of cost function models are estimated. They differ with respect to the specification of the intercept in the regression model. In the first set of models region-specific fixed effects are implemented, thus allowing for shifts in the cost function for farms in different regions. In the second set, firm-specific fixed effects are implemented. This implies that the cost function of firms in the same region can have different positions. Region-specific effects represent biophysical factors, such as sea temperatures and currents, which have a large influence on productivity. There can, however, also be significant differences in biophysical conditions between farm sites in the same region. This provides an argument for firm-specific effects in stead of region-specific effects. The reason for using region-specific effects is that we are forced to exclude firms that are only observed one year with firm-specific effects. There may be selection biases associated with the exclusion of these firms since firm exit can be influenced by agglomeration economies. The sample is reduced from 2,638 observations to 2,566 observations. Both sets of models are estimated here, to test the robustness of the empirical results related to agglomeration economies.[9]

[9] One could have estimated a model with both region-specific effects and firm-specific effects, where one of the effects were specified as fixed and one as random. However, the correlation between these effects and other variables in the model can lead to biased parameter estimates. This has been shown for this particular industry by Tveteras (1997, Ch. 9).

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

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

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. In the second set of models the terms $\Sigma_r\mu_r$ are replaced by the firm-specific fixed effects $\Sigma_i\mu_i$.

The agglomeration function is specified as:

$$(2)\qquad E(FD, RE; \beta) = \beta_{FD}\ln FD + 0.5\beta_{FD2}\ln FD^2 + \beta_{RE}\ln RE + 0.5\beta_{RE2}\ln RE^2$$
$$+ \beta_{FD\ RE}\ln FD\ \ln RE + \Sigma_i\beta_{FD,i}\ln FD\ \ln w_i + \Sigma_i\beta_{RE,i}\ln RE\ \ln w_i$$
$$+ \beta_{FD\ y}\ln FD\ \ln y + \beta_{RE\ y}\ln RE\ \ln y + \beta_{FD\ t}\ln FD\ t + \beta_{RE\ t}\ln RE\ t.$$

This specification is flexible enough to allow testing of a number of hypotheses on the structure of agglomeration externalities. For example, if the marginal effect of agglomeration externalities on productivity are positive but decreasing ($\beta_{FD} > 0$ and $\beta_{FD2} < 0$; $\beta_{RE} > 0$ and $\beta_{RE2} < 0$), if agglomeration externalities are scale enhancing ($\beta_{FD\ y} \neq 0$; $\beta_{RE\ y} \neq 0$), are input-biased ($\beta_{FD,i} \neq 0$; $\beta_{RE,i} \neq 0$, for some i), or if the size of agglomeration externalities have changed over time ($\beta_{FD\ t} \neq 0$; $\beta_{RE\ t} \neq 0$). 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).[10] 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.

Returns to scale is defined as

$$(3)\qquad \varepsilon_y = 1/(\partial\ln C/\partial\ln y)$$

[10] 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).

The conditional own price elasticity of demand for input i is defined as

(4) $\varepsilon_i = (\alpha_{ii} + S_i^2 - S_i)/S_i$, i = Feed, Labor, Capital.

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

(5) $\varepsilon_{FD} = \partial \ln C/\partial \ln FD = \beta_{FD}\ln FD + \beta_{FD2}\ln FD + \beta_{FD\ RE}\ln RE + \Sigma_i\beta_{FD,i}\ln w_i + \beta_{FD\ y}\ln y + \beta_{FD\ t}t$,

(6) $\varepsilon_{RE} = \partial \ln C/\partial \ln RE = \beta_{RE}\ln RE + \beta_{RE2}\ln RE + \beta_{FD\ RE}\ln FD + \Sigma_i\beta_{RE,i}\ln w_i + \beta_{RE\ y}\ln y + \beta_{RE\ t}t$,

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, and (2) shifts in the production frontier through localized knowledge spillovers. 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).

Three different definitions of costs *C* were used in the estimation of the translog cost model. In the first model specification (denoted R1 and F1 for the model with region- and firm-specific intercepts, respectively) feed, labor and capital costs are included. Then, the estimated parameters associated with the agglomeration indexes *FD* and *RE* will necessarily only capture cost savings related to these three inputs. The ambition here is to estimate the effects of agglomeration on the total costs of production. To accommodate for this, two other models which include other cost categories were estimated. In one model (R2 and F2), the costs associated with intermediate material and producers service purchases are added to the other costs. Finally, smolts costs are added together with materials and services in the third specification (R3 and F3).[11] Hence the second and third cost definition allow testing of a broader set of agglomeration externalities than the first definition. It should be noted that when only feed, labor 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 smolts input in salmon farming. For materials and services inputs 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 smolts costs are included in the dependent variable in models R2/F2 and R3/F3. Despite the potential biases associated with the absence of these input prices, it was decided to estimate models with materials, services and smolts 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 models R2/F2 and R3/F3are assessed.[12]

One could argue that separate regression models could be estimated for the cost categories where input prices are not observed to explain the influence of agglomeration effects. A cost model for, e.g., materials and services costs, should include other variables which influence the level of these costs, such as prices of observed inputs, output, region-specific effect and time-specific effects. However, agglomeration may not necessarily bring about a reduction in materials and services 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

[11] 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 sea water.
[12] For example, technological progress embodied in materials, services and smolts inputs should be captured by the time trend variable parameters. But so could time trends in the unobserved prices of these inputs.

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 & Siegel (1999) points 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 report. 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:

$$(7) \qquad \ln VC = \Sigma_r\mu_r + \Sigma_i\alpha_i \ln w_i + 0.5\Sigma_i\Sigma_j\alpha_{ij}\ln w_i \ln w_j + \alpha_z \ln z + 0.5\alpha_{zz}(\ln z)^2 + \alpha_y \ln y$$
$$+ 0.5\alpha_{yy}(\ln y)^2 + \Sigma_i\alpha_{iZ}\ln w_i \ln z + \Sigma_i\alpha_{iy}\ln w_i \ln y + \alpha_{zy}\ln z \ln y + \alpha_t t + 0.5\alpha_{tt}t^2$$
$$+ \Sigma_i\alpha_{it}\ln w_i\ t + \alpha_{zt}\ln z\ t + \alpha_{yt}\ln y\ t + E(FD, RE\ ;\ \beta) + u,$$

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) is estimated. The agglomeration function $E(FD, RE\ ;\ \beta)$ is specified as in (2), except that the two terms involving the price of capital are replaced by the terms $\beta_{FD\ z}\ln FD\ \ln z$ + $\beta_{RE\ z}\ln RE\ \ln z$. The variable cost function is estimated together with the cost share equation for fish feed using Zellner's SURE. Short-run and long-run returns to scale is now $\varepsilon_{y\text{-}SR} = 1/(\partial \ln C/\partial \ln y)$ and $\varepsilon_{y\text{-}LR} = (1 - \partial \ln C/\partial \ln z)/(\partial \ln C/\partial \ln y)$, respectively (Caves, Christensen and Swanson, 1981). As before, the cost elasticity with respect to the agglomeration indexes FD and RE is found by taking logarithmic partial derivatives, i.e. $\varepsilon_{FD} = \partial \ln C/\partial \ln FD$ and $\varepsilon_{RE} = \partial \ln C/\partial \ln RE$.

5. Empirical Results

This section discusses the empirical results from estimation of the translog cost model (1)-(2) on the sample of Norwegian salmon aquaculture firms. The results from the cost models with region specific intercepts; R1-R3, are presented first, and then the discussion turns to the models with firm-specific effects, F1-F2.

Table 2 provides the estimated parameters from the translog cost models R1-R3, and Table 3 presents the associated elasticity estimates. More restricted specifications of the agglomeration function (2) were tested for each of these models. For all three 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 all three models R1-R3. 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 and R3 have 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 elasticitiy for feed, labor and capital are –0.102, -0.205 and –0.256, respectively.[13] The calculated own price elasticities from models R2 and R3 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 1.5% in Model B to 3.5% in Model A 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 report. According to Table 3 the elasticity of cost in regional industry size, ε_{RE}, is -17.5% in model R1, -18.6% in model R2 and –13.8% in model R3 for the sample average firm. Hence, all 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 indicating cost savings; for the sample average farm the estimated elasticity from models R1, R2 and R3 are -6.0%, -5.8% and –0.8%, respectively.

To show more clearly the economic significance of agglomeration externalities it can

[13] Both for 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).

be useful to plot the predicted unit costs from the estimated models R1-R3. Unit costs are shown in Figure 1 for different regional industry sizes, and in Figure 2 for different region 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 corresponds to the sample range. [14] We see that costs decline significantly in economic terms for all three cost definitions in industry size. The effect of regional farm density is much weaker, and benefits from physical proximity seem to be exhausted at high densities.

Next, the empirical results from the three translog cost models with firm-specific intercepts (F1-F3) are discussed. Parameter estimates and calculated elasticities from models F1-F3 are provided in Table 4 and Table 5, respectively. Likelihood-ratio tests of region-specific effects versus the more general model with firm-specific effects lead to a rejection of the model specification with region-specific effects in all cases.

A comparison of elasticities calculated from the models with region-specific effects (R1-R3) and the models with firm-specific effects (F1-F3) shows that returns to scale (ε_Y) is somewhat higher for the models with firm effects, while the estimated rate of technical change (*TC*) is lower (in absolute value) for the sample mean farm. The cost elasticity with respect to regional industry size (ε_{RE}) is significantly lower for all three models. In fact, for models F1-F3 the estimates of ε_{RE} are between 1/3 and 1/4 of the estimated values from R1-R3. On the other hand, we find that the cost elasticity with respect to regional farm density (ε_{FD}) is higher in the firm-effects models F1-F3 than the region-effects models R1-R3.

The predicted unit costs from the models F1-F3 are plotted in Figure 3 for different regional industry sizes, and in Figure 4 for different region farm densities. By comparing Figure 1 with Figure 3, we see that the relationship between regional industry size and unit costs is weaker for models F1-F3 than models R1-R3. On the other hand, we see from Figure 2 and 4 that there is a stronger relationship between regional farm density and predicted unit cost in the models with firm-specific effects.

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 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

[14] Then (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 kilometers.

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 $\beta_{FD\ t}$ and $\beta_{RE\ t}$ parameters. However, the estimates of these parameters are not significantly different from zero in any of the models reported in Table 2 and 4. Furthermore, an examination of the individual components of the estimated elasticities ε_{FD} and ε_{RE}, cf. equations (5) and (6), reveals that the term involving the time trend variable has relatively little influence on the elasticity estimate for both ε_{FD} and ε_{RE}.[15] Overall, these results suggest that the size of agglomeration effects on costs have 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 (5) and (6), is the dominant factor explaining the elasticity estimates for both regional industry size and farm density. The 'internal scale' parameter $\beta_{RE\ Y}$ 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 $\beta_{FD\ Y}$ 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 ($\beta_{RE\ F}$, $\beta_{RE\ L}$, $\beta_{RE\ K}$, $\beta_{FD\ F}$, $\beta_{FD\ L}$, $\beta_{FD\ K}$).

Next, we examine the empirical results from the short-run variable cost functions, as specified in (7). Table 6 reports the parameter estimates from the model with region-specific intercepts (Model SRR) and the model with firm-specific intercepts (Model SRF), and Table 7 provides the derived elasticity estimates. In both models most of the parameters associated with the quasi-fixed capital input are significant at conventional confidence levels, thus providing support for the short-run specification. The models provide very different estimates of long-run returns to scale ($\varepsilon_{y\text{-}LR}$), with a sample mean value of 1.142 and 1.623 for models SRR and SRF, respectively.

What are the predictions from the estimated short-run cost function on agglomeration economies? The elasticity of variable costs with respect to regional industry size (*RE*) is –19.1% and –8.9% for the region- and firm-specific intercepts model, respectively. Hence, there are short-run cost savings associated with increasing industry size, even when we include only feed and labor costs. For regional farm density we also find cost savings in the

[15] The estimated values of the individual terms of equations (5) and (6) are not reported in the tables.

short run, but these are small, with mean elasticity of –2.9% for model SRR and –4.8% for model SRF.

6. Summary and Conclusions

This report 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-run and short-run cost functions, with different cost definitions, were estimated. 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 testing of the influence of agglomeration externalities on a subset of input costs in salmon farming. Hence, while recognizing potential biases, long-run specifications which included a wider range of inputs was 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 are robust to changes in econometric model specifications. Cost savings are found to be associated with both increasing regional industry size and with regional farm density.

The results in this report 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 loose 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 with 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 lead 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 other 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 to 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 Scotland and Chile, 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 agglomeration economies as found in this report 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.

The results here provide empirical support for the presence of agglomeration externalities in Norwegian salmon aquaculture. Future research should investigate the effects of increased firm concentration on these externalities, and linkages between salmon aquaculture and related industries. At a more general level, separate identification of the size of pecuniary externalities and knowledge externalities in a dual econometric model framework certainly deserves more attention.

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Table 1. Summary Statistics for Salmon Firms

Variable	Entire sample		Regional sample mean values[10]								
	Mean	Std.Dev.	R	H	SF	MR	ST	NT	N	T	F
Costs[1,2]	4716752	3041432	4070475	5754458	4883708	5269188	4702613	3817383	4312274	3813949	3932437
Feed cost[1]	3294220	2356001	2901422	4094342	3410319	3732338	3088293	2569785	3050092	2669322	2483579
Capital cost[1,3]	503192	453157	384227	644800	531309	539733	590549	419042	399643	356219	611781
Labor cost[1]	919340	570209	784826	1015315	942080	997117	1023771	828555	862539	788408	837077
Output[4]	276985	238695	244471	345099	295288	294863	254764	213979	260124	241407	218589
Price feed[1,5]	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[1,6]	0,20	0,17	0,19	0,20	0,20	0,20	0,21	0,20	0,19	0,19	0,17
Materials & services[7]	1135013	1144419	923993	1292180	1040228	1264686	1219897	981994	1121886	1002187	1075883
Harvest cost	375108	743701	371944	400824	249696	348350	351180	268979	480220	508961	285406
Freight cost	64605	154369	44337	49353	16385	86339	51275	58776	120881	58575	45809
Smolt cost	1533148	971156	1355389	1737136	1606195	1686099	1411824	1360801	1502468	1308710	1317280
Reg. empl.[8]	752,22	297,52	342,99	1151,51	553,30	868,28	558,14	399,27	937,11	574,07	569,33
Farm density[9]	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.	2638		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. Costs is the sum of feed, capital and labor costs.
3. Capital cost is defined as depreciation costs based on replacement value plus a user cost calculated as 7% of total capital.
4. Output is measured as the fish harvest in kg, plus the change in stock of live fish in the pens during the year.
5. 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.
6. The price of capital is defined as the capital cost divided by total capital..
7. Materials and services are measured by expenditures on maintenance and repairs, electricity, office equipment, rent of equipment and buildings, producer services etc.
8. Regional employment is measured in 1000 man-hours, and includes all stages of salmon production (broodstock and roe, fry, smolts, and farmed fish).
9. Farm density is measured as the number of farms per square km sea area.
10. 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).

Table 2. Estimated Parameters of Translog Long-Run Cost Functions with Region-Specific Effects

Parameters		Model R1		Model R2		Model R3	
		Coeff.	**T-ratio**	**Coeff.**	**T-ratio**	**Coeff.**	**T-ratio**
Region-specific fixed effects	α_R	15.348	325.759	15.419	310.121	15.735	314.030
	α_H	15.605	626.834	15.708	577.827	15.983	583.164
	α_{SF}	15.449	653.518	15.541	603.320	15.832	609.276
	α_{MR}	15.544	657.321	15.652	607.879	15.926	613.587
	α_{ST}	15.455	486.601	15.572	460.808	15.832	465.053
	α_{NT}	15.389	549.977	15.489	513.535	15.781	518.955
	α_N	15.466	320.693	15.602	305.146	15.844	307.690
	α_T	15.378	327.662	15.508	313.893	15.754	316.637
	α_F	15.425	313.783	15.538	299.907	15.787	302.563
Output level and input price variables	α_y	0.855	46.419	0.838	43.085	0.788	40.155
	α_{y2}	0.071	7.528	0.072	7.276	0.087	8.823
	α_{Feed}	0.659	128.401	0.585	99.050	0.443	88.174
	α_{Labor}	0.214	58.710	0.187	61.893	0.142	56.609
	$\alpha_{Kapital}$	0.128	31.578	-0.027	-0.864	-0.004	-0.127
	α_{FF}	0.145	42.627	0.176	42.510	0.178	50.919
	α_{FL}	-0.102	-43.080	-0.062	-26.591	-0.034	-17.335
	α_{FK}	-0.043	-17.793	0.020	4.183	0.008	1.921
	α_{LL}	0.104	41.230	0.079	30.333	0.064	29.359
	α_{LK}	-0.002	-0.989	0.001	0.432	-0.003	-1.405
	α_{KK}	0.045	17.623	-0.012	-0.843	-0.015	-1.113
	α_{yF}	0.090	31.489	0.086	26.350	0.083	30.076
	α_{yL}	-0.066	-32.319	-0.047	-27.657	-0.029	-21.137
	α_{yK}	-0.024	-10.681	0.011	0.882	-0.004	-0.288
Time trend variables and interaction with output and input prices	α_t	0.052	7.452	0.076	10.183	0.066	8.776
	α_{t2}	-0.014	-14.112	-0.015	-14.085	-0.015	-13.738
	α_{yt}	0.000	0.064	-0.002	-0.855	-0.001	-0.533
	α_{Ft}	0.009	12.365	-0.003	-4.057	0.002	2.311
	α_{Lt}	-0.005	-9.621	-0.007	-16.292	-0.004	-11.995
	α_{Kt}	-0.004	-7.018	0.000	0.060	-0.001	-0.218
Agglomeration variables and interaction with other variables	β_{RE}	-0.173	-4.744	-0.203	-5.235	-0.151	-3.860
	β_{RE2}	-0.019	-0.409	0.006	0.119	0.005	0.098
	$\beta_{RE\cdot y}$	-0.014	-1.216	-0.015	-1.254	-0.014	-1.188
	$\beta_{RE\cdot F}$	-0.004	-0.957	-0.006	-1.307	-0.008	-2.258
	$\beta_{RE\cdot L}$	-0.006	-2.131	-0.005	-2.004	-0.005	-2.680
	$\beta_{RE\cdot K}$	0.009	3.144	-0.003	-0.160	0.007	0.383
	$\beta_{RE\cdot t}$	-0.003	-0.992	0.000	-0.122	-0.001	-0.323
	β_{FD}	-0.051	-1.437	-0.044	-1.203	-0.063	-1.699
	β_{FD2}	0.058	2.007	0.058	1.944	0.053	1.774
	$\beta_{FD\cdot y}$	0.011	1.860	0.012	1.905	0.016	2.505
	$\beta_{FD\cdot F}$	0.016	7.423	0.024	9.986	0.018	8.724
	$\beta_{FD\cdot L}$	-0.015	-10.277	-0.008	-6.779	-0.006	-5.815
	$\beta_{FD\cdot K}$	0.000	-0.166	0.013	1.262	0.010	0.960
	$\beta_{FD\cdot t}$	0.001	0.595	0.000	0.281	0.000	-0.106
	$\beta_{RE\cdot FD}$	-0.038	-1.204	-0.057	-1.678	-0.057	-1.689
Log-likelihood		9470.13		8939.89		9935.13	
R-squared		0.9998		0.9998		0.9998	

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

Table 3. Elasticity Estimates from Long-Run Cost Functions with Region-Specific Effects*

Elasticity	Model R1		Model R2		Model R3	
	Mean	St. Err.	Mean	St. Err.	Mean	St. Err.
ε_y	1.206	0.076	1.260	0.078	1.349	0.116
ε_{Feed}	-0.102	0.068	-0.123	0.051	-0.122	0.091
ε_{Labor}	-0.205	0.295	-0.241	0.375	-0.267	0.378
$\varepsilon_{Capital}$	-0.256	1.009	-1.140	0.456	-1.311	0.678
TC	-0.035	0.045	-0.015	0.048	-0.024	0.047
ε_{RE}	-0.175	0.040	-0.186	0.048	-0.138	0.049
ε_{FD}	-0.060	0.046	-0.058	0.049	-0.080	0.046

* Elasticities are evaluated at the sample mean level of the regressors.

Table 4. Estimated Parameters of Translog Long-Run Cost Functions with Firm-Specific Effects*

Parameters		**Model F1**		**Model F2**		**Model F3**	
		Coeff.	**T-ratio**	**Coeff.**	**T-ratio**	**Coeff.**	**T-ratio**
Output level and input price variables	α_y	0.809	46.196	0.788	46.347	0.722	42.334
	α_{y2}	0.068	7.425	0.059	6.755	0.072	8.240
	α_{Feed}	0.663	130.480	0.590	99.610	0.446	89.658
	α_{Labor}	0.211	58.396	0.185	61.005	0.140	57.236
	α_{Kapital}	0.126	34.759	-0.026	-0.975	-0.011	-0.428
	α_{FF}	0.145	43.842	0.178	48.537	0.177	57.720
	α_{FL}	-0.101	-41.841	-0.065	-28.495	-0.036	-19.298
	α_{FK}	-0.044	-20.737	0.018	3.767	0.005	1.356
	α_{LL}	0.102	40.544	0.077	29.341	0.061	28.648
	α_{LK}	-0.001	-0.717	0.001	0.247	-0.003	-1.755
	α_{KK}	0.046	21.353	-0.023	-1.979	-0.022	-1.923
	α_{yF}	0.092	32.032	0.087	26.739	0.084	30.733
	α_{yL}	-0.067	-32.303	-0.048	-28.052	-0.030	-21.846
	α_{yK}	-0.025	-12.340	0.005	0.502	-0.008	-0.779
Time trend variables and interaction with output and input prices	α_t	0.051	8.254	0.071	11.611	0.065	10.703
	α_{t2}	-0.012	-14.098	-0.012	-14.303	-0.013	-14.770
	α_{yt}	-0.002	-0.750	-0.004	-2.037	-0.003	-1.305
	α_{Ft}	0.008	11.623	-0.004	-4.971	0.001	1.662
	α_{Lt}	-0.004	-8.933	-0.006	-15.550	-0.004	-11.698
	α_{Kt}	-0.004	-7.352	0.000	-0.098	0.001	0.250
Agglomeration variables and interaction with other variables	β_{RE}	-0.069	-2.155	-0.075	-2.360	-0.047	-1.485
	β_{RE2}	-0.058	-1.489	-0.045	-1.194	-0.045	-1.211
	$\beta_{RE\cdot y}$	-0.013	-1.187	-0.014	-1.247	-0.018	-1.661
	$\beta_{RE\cdot F}$	-0.005	-1.208	-0.007	-1.687	-0.010	-2.633
	$\beta_{RE\cdot L}$	-0.005	-1.851	-0.004	-1.579	-0.004	-2.448
	$\beta_{RE\cdot K}$	0.010	3.544	-0.002	-0.151	0.004	0.262
	$\beta_{RE\cdot t}$	-0.001	-0.372	0.000	0.176	0.000	0.005
	β_{FD}	-0.085	-2.778	-0.087	-2.956	-0.073	-2.479
	β_{FD2}	0.007	0.274	-0.003	-0.127	0.001	0.040
	$\beta_{FD\cdot y}$	0.020	3.014	0.025	3.860	0.029	4.578
	$\beta_{FD\cdot F}$	0.015	7.319	0.024	9.846	0.018	8.993
	$\beta_{FD\cdot L}$	-0.015	-10.076	-0.008	-6.318	-0.006	-5.535
	$\beta_{FD\cdot K}$	0.000	-0.197	-0.009	-1.115	-0.011	-1.364
	$\beta_{FD\cdot t}$	0.001	0.839	0.001	0.542	-0.001	-0.489
	$\beta_{RE\cdot FD}$	0.015	0.552	0.017	0.659	0.016	0.606
Log-likelihood		9771.22		9234.90		10220.8	
R-squared							

*Firm-specific intercepts are not reported due to space considerations.

Table 5. Elasticity Estimates from Long-Run Cost Functions with Firm-Specific Effects*

Elasticity	Model F1		Model F2		Model F3	
	Mean	St. Err.	Mean	St. Err.	Mean	St. Err.
ε_y	1.297	0.085	1.365	0.082	1.493	0.122
ε_{Feed}	-0.101	0.068	-0.119	0.051	-0.124	0.091
ε_{Labor}	-0.214	0.291	-0.261	0.364	-0.292	0.363
$\varepsilon_{Capital}$	-0.245	1.019	-1.361	0.872	-1.477	0.957
TC	-0.025	0.041	-0.004	0.041	-0.012	0.041
ε_{RE}	-0.070	0.029	-0.068	0.024	-0.041	0.026
ε_{FD}	-0.086	0.020	-0.091	0.021	-0.088	0.022

* Elasticities are evaluated at the sample mean level of the regressors.

Table 6. Estimated Parameters of Translog Short-Run Cost Functions*

Parameters		Model SRR		Model SRF	
		Coeff.	T-ratio	Coeff.	T-ratio
Output level, input price and quasi-fixed input variables	α_y	0.881	46.480	0.821	41.395
	α_{y2}	0.096	9.460	0.109	10.543
	α_{Feed}	0.772	188.020	0.660	130.310
	α_{Labor}	0.228	55.400	0.340	67.061
	α_{FF}	0.125	48.910	0.117	38.858
	α_{FL}	-0.125	-48.910	-0.117	-38.858
	α_{LL}	0.125	48.910	0.117	38.858
	α_z	0.015	1.310	-0.130	-5.969
	α_{z2}	0.015	2.860	0.119	8.213
	α_{FZ}	-0.033	-18.860	0.035	4.334
	α_{LZ}	0.033	18.860	-0.035	-4.334
	$\alpha_{y\mathrm{F}}$	0.105	41.510	0.082	29.033
	$\alpha_{y\mathrm{L}}$	-0.105	-41.510	-0.082	-29.033
	α_{yz}	-0.041	-6.950	0.001	0.066
Time trend variables and interaction with output, input prices, and quasi-fixed input	α_{t}	0.043	6.500	0.050	7.095
	α_{t2}	-0.011	-11.310	-0.012	-12.014
	$\alpha_{y\mathrm{t}}$	-0.005	-2.130	-0.005	-1.999
	α_{Ft}	0.003	5.320	0.008	12.253
	α_{Lt}	-0.003	-5.320	-0.008	-12.253
	$\alpha_{z\mathrm{t}}$	0.006	3.860	-0.014	-11.648
Agglomeration variables and interaction with other variables	β_{RE}	-0.185	-5.570	-0.119	-3.224
	β_{RE2}	-0.023	-0.560	-0.029	-0.641
	$\beta_{\mathrm{RE}\cdot y}$	-0.012	-1.110	-0.039	-3.064
	$\beta_{\mathrm{RE\cdot F}}$	0.007	2.340	-0.001	-0.293
	$\beta_{\mathrm{RE\cdot L}}$	-0.007	-2.340	0.001	0.293
	$\beta_{\mathrm{RE}\cdot z}$	0.015	1.880	-0.011	-0.638
	$\beta_{\mathrm{RE\cdot t}}$	-0.003	-0.970	0.004	1.192
	β_{FD}	-0.021	-0.640	-0.049	-1.418
	β_{FD2}	0.033	1.270	0.015	0.543
	$\beta_{\mathrm{FD}\cdot y}$	0.016	2.680	0.026	3.410
	$\beta_{\mathrm{FD\cdot F}}$	0.019	11.610	0.016	7.558
	$\beta_{\mathrm{FD\cdot L}}$	-0.019	-11.610	-0.016	-7.558
	$\beta_{\mathrm{FD}\cdot z}$	-0.004	-0.940	-0.005	-0.547
	$\beta_{\mathrm{FD\cdot t}}$	0.000	0.140	0.002	1.350
	$\beta_{\mathrm{RE\cdot FD}}$	-0.030	-1.060	0.024	0.770
Log-likelihood		5537.18		4874.68	
No. of obs.		2638		2566	

*Regions-specific and firm-specific intercepts are not reported due to space considerations.

Table 7. Elasticity Estimates from Translog Short-Run Cost Functions*

Elasticity	Model SRR		Model SRF	
	Mean	St. Err.	Mean	St. Err.
$\varepsilon_{y\text{-}SR}$	1.217	0.092	1.340	0.135
$\varepsilon_{y\text{-}LR}$	1.142	0.063	1.623	0.151
ε_{Feed}	-0.072	0.061	-0.143	0.056
ε_{Labor}	-0.266	2.991	-0.286	0.088
TC	-0.025	0.038	-0.025	0.042
ε_{RE}	-0.191	0.035	-0.089	0.032
ε_{FD}	-0.029	0.029	-0.048	0.031

* Elasticities are evaluated at the sample mean level of the regressors.

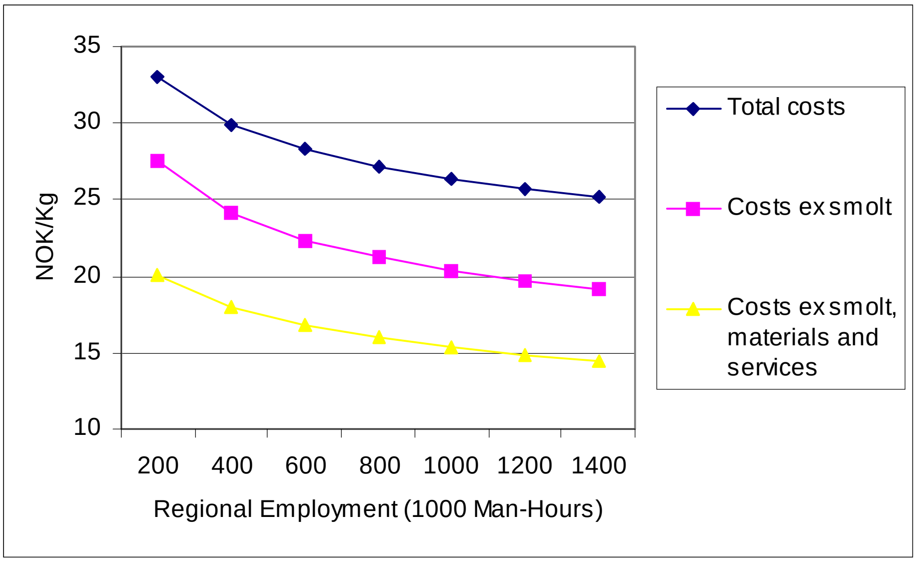

Figure 1. Estimated Unit Production Costs for Different Regional Industry Sizes from Models R1-R3

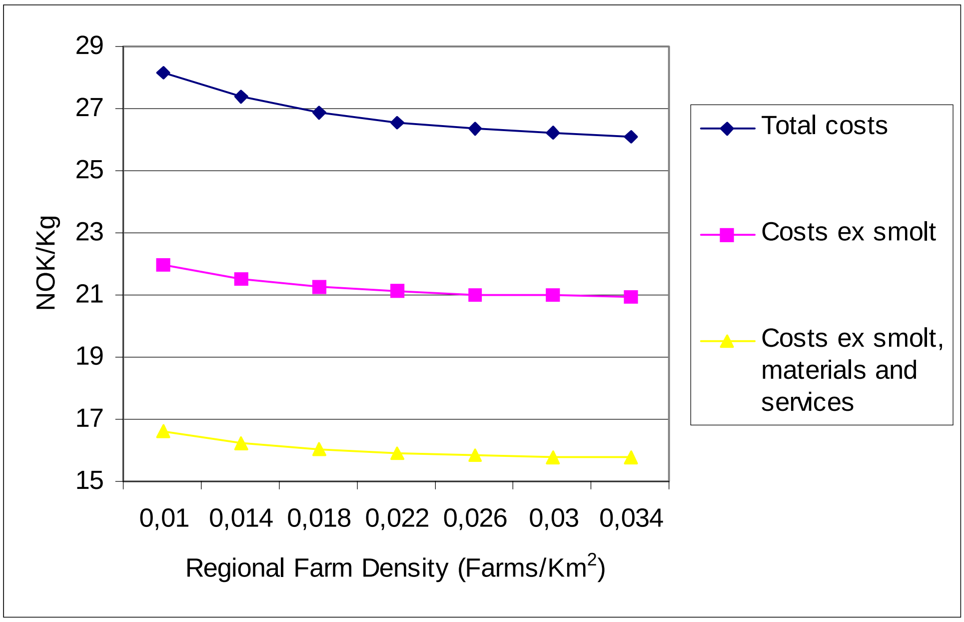

Figure 2. Estimated Unit Production Costs in For Different Regional Farm Density Levels from Models R1-R3

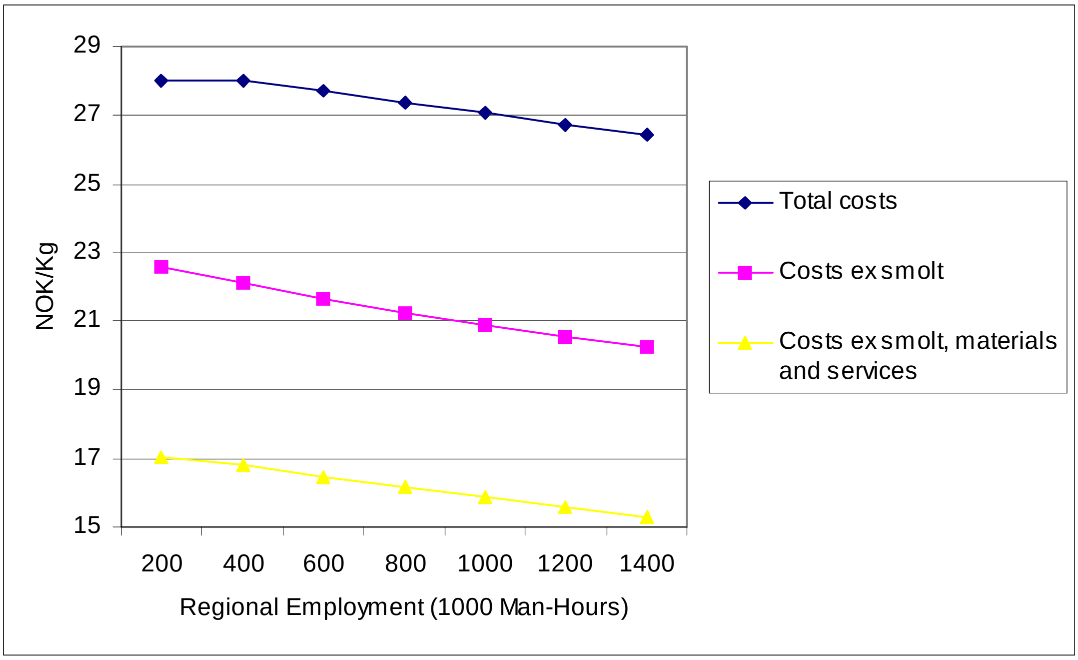

Figure 3. Estimated Unit Production Costs for Different Regional Industry Sizes from Models F1-F3

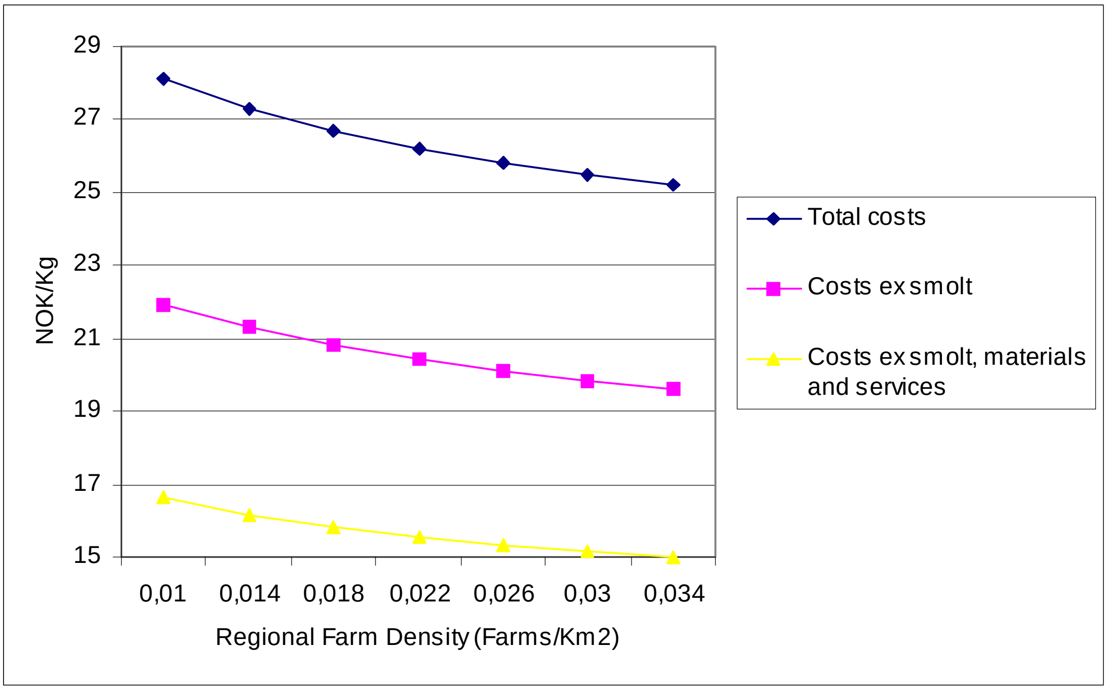

Figure 4. Estimated Unit Production Costs in For Different Regional Farm Density Levels from Models F1-F3