UiT
THE ARCTIC UNIVERSITY OF NORWAY

Faculty of Biosciences, Fisheries and Economics,
School of Business and Economics

Just Like Putting Scissors to a Market

Investigating Supply and Demand Relations of Farmed Atlantic Salmon

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Sverre Braathen Thyholdt

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I. Summary

Price and quantity numbers, which we are observing in a market place, occur because of an interaction between supply and demand. An understanding of what drives supply and demand is therefore important in order to understand the market in itself. This dissertation focuses on determining the impact of exogenous factors on salmon biomass growth and how producers respond to price changes. Furthermore, we determine the total demand growth and the factors affecting demand growth in the global salmon market.

The first paper determines the importance of temperature in the growth of Norwegian farmed salmon for three different regions. The results show that sea temperature is a critical factor to explain growth. Periods with higher sea temperatures lead to faster growth in the North and Central regions, while leading to slower growth in the South.

In the second paper, salmon farmers' response to price changes are estimated for three different regions in Norway. We find that the salmon producers are responding to price changes in the long run, while there are limited responses to price changes in the short run. The long-run response differs from region to region, and the own-price supply elasticity is 1.22 for the Northern region, 1.39 for the Central region, and 0.58 for the Southern region, with a national average of 1.06.

The third paper determines the magnitude of the shifts in annual demand across all major salmon importing regions in the world. Results indicate that demand varies considerably between years and regions and does not appear to follow a smooth trend, which is usually assumed in empirical analysis.

The fourth paper extends the procedure of the third. We disentangle the impacts from income growth and price changes in substitute products from total demand shift. The remaining residual shift in demand is due to other unknown or omitted factors. Results indicate that demand shifts due to unknown factors account for a large portion of total demand growth in all regions, and this residual growth is not smooth in any region. The results demonstrate that any demand analysis focusing only on relative prices, income, and a trend variable will not appropriately account for the large variation in salmon demand in any region.

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IV. List of Papers

Paper 1

Thyholdt, S. B. 2014.

"The Importance of Temperature in Farmed Salmon Growth: Regional Growth Functions for Norwegian Farmed Salmon." *Aquaculture Economics & Management* 18(2):189–204.

Paper 2

Thyholdt, S. B.

“Regional Supply Response of Norwegian Farmed Salmon”

Submitted to *Aquaculture Economics & Management*

Paper 3

Brækkan, E. H., and S. B. Thyholdt. 2014.

"The Bumpy Road of Demand Growth — An Application to Atlantic Salmon." *Marine Resource Economics 29(4):339-50*

Paper 4

Brækkan, E. H., S. B. Thyholdt, and Ø. Myrland

“The Demands They Are a-Changin’”

1. Introduction

Price and quantity figures we are observing in a market place occur because of an interaction between supply and demand. An understanding of what drives supply and demand is therefore important in order to understand the market in itself. One must then know what factors cause demand or supply to grow to understand the price formation in the market place.

This dissertation focuses on the farmed salmon market. Since the introduction of aquaculture in the early 1980s, the global supply of farmed salmon has increased from a few thousand tons in 1980 to over 2 million tons in 2010. Over the last few decades, aquaculture has represented the fastest-growing animal-based food production technology (FAO 2012; Smith et al. 2010), and salmon production has grown faster than aquaculture production in aggregate. Improved technology in the beginning of this period has caused prices to drop considerably until the early 2000s. Since then, prices have slightly increased, with continuing quantity growth. This suggests that demand growth is outpacing supply. The increased control over the production process has led to productivity growth and increased efficiency, and temporary shocks account for the remaining inefficiency. The papers in this dissertation focus on the impact of exogenous factors on salmon biomass growth and how producers respond to price changes. Furthermore, we determine the total demand growth and the factors affecting demand growth in the global salmon market.

This dissertation begins with a discussion about the theories behind demand and supply. Then, an overview of the characteristics of the salmon market is presented, followed by a presentation of the papers in this dissertation.

2. Demand and Supply; Theories and Application

Observed price and quantity figures in a market are the result of an interaction between supply and demand, which are fundamental concepts for any economists. Cournot (1838, p. 41) described the law of demand as follows: "the sales or the demand generally… increases when the price decreases", and Marshall (1920, p. 84) defines the general law of demand similarly to Cournot: "the amount demanded increases with a fall in price and diminishes with a rise in price". In demand analysis, this is an essential assumption.

Supply is the quantity of a good available for sale at any given price. The fundamental principle is that an increase in price results in an increase in quantity supplied. Henderson (1922, p. 18) states that "price tends to the level at which demand equals supply". This assertion is in line with Marshall (1920), who states that demand and supply determine prices and are as important as either blade on a pair of scissors.

Estimating price responses for consumers and producers have been going on for about a century. Henry L. Moore attempted in 1914 to measure the quantitative relationship between prices and consumption (Stigler 1962; Waugh 1964). A decade later, the first statistical studies of supply response analysis was conducted (Mundlak 2001). Difficulties in measuring the responses occurred early. In Moore's attempt in 1914, he famously announced he had found an upward-bending demand curve for pig-iron (Heckman 1992), in which Philip Wright (1915) made him aware that he had probably just found the supply curve. This led the father-and-son research team of Philip and Sewall Wright to try to determine how to estimate the slope of supply and demand curves when the only thing we observe are equilibrium price and quantitative figures (Angrist and Pischke 2009). This, which outlines the problem with the occurrence of several endogenous variables, laid the foundation for the development of instrumental variables and simultaneous equations modelling used in Marschak and Andrews' (1944) work related to the production function and Haavelmo's (1943, 1947) work in terms of the consumption function.

The introduction of statistical methods in economics was met with both delight and despair. Frisch, who is considered the founder of the term *econometrics*, declared in the founding issue of the journal *Econometrica* that econometrics would take over economics and be the way forward (Magnus and Morgan 1987). The popular Keynes-Tinbergen debate in *The Economic Journal* between 1939-40 has often been used as an example to discredit econometrics. However, the debate should probably be understood as a discussion on *how* to use statistics in economics, not *if* statistics should be used (Jolink 2000; Wood 1994). Still, Keynes was against the idea that an econometric model could be a source of new economic ideas, and he meant that if an empirical model contradicted the theory, then the data were wrong, not the theory (Heckman 1992). Keynes defined economics as "a science of thinking in terms of models joined to the art of choosing models which are relevant to the contemporary world" (Keynes 1994, p. 168). Frisch also stressed the importance of theory when trying to draw information about the economic interrelationship from observed data, or else one would be led to believe that the tourists that visited western Norway in the summer did so because of the number of flies (Haavelmo 1997). The distinction between theoretical models, which is considered a behavioural entity, and fitted equations were useful for causal investigations and policy analysis (Heckman 1992). However, the use of observational data to determine causal relationships has not been appreciated by many statisticians (Angrist and Pischke 2009; Heckman 1992). Rubin (1974) and Holland's (1986) statements that there can be "no causation without manipulation" have often been interpreted to rule out causal inference with the use of non-experimental data, but they assert that an effect requires several causes and this could also be possible to test for using observational data.

2.1 Supply and Production

The supplier's long-run decision problem is to plan an output and input combination to maximize profit. The optimal production level is obtained where marginal revenue equals marginal cost. In the presence of uncertainty, the supplier must find the appropriate balance between maximizing expected profits and minimizing risk.

In the estimation of supply and demand, it was established early that supply analysis was more complicated and difficult compared to demand analysis (Cassels 1933). Twenty years later, Schultz (1956) argues similarly. The reason, argued by Schultz, is that, for a function to be useful, it has to be stable over time; if it is not stable, we should be able to predict how it will change. The stability of the demand function is reliant on what happens to "tastes", and the stability of the supply function is reliant on what happens to "technology"; tastes are fairly constant over time, while technology is not. This is because part of the change in technology is unpredictable, and not all improvements in technology will actually be implemented.

Other issues that complicate the estimation of agricultural supply responses are due to the gap between seedtime and harvest, since the production of food does take a significant period of time. This presents uncertainty for the producers and complicates the possibility to give an immediate response to a change in price. Due to this time lag, the producers must make a production decision based on their expectations of the future price for the product produced as well as the price for their future inputs. This has led to a discussion about how producers form their expectations, since supply (and demand) depends in general not only on current prices but also on expectations (Arrow and Nerlove 1958). Fluctuation in prices within agricultural markets and the appearance of business and economic cycles were, and still are, of interest for many economists (Heckman 1992), and this in part could be explained by expectations. The supporters of the Cobweb Theorem, which was expounded in the 1930s, based their assumption on the economic agent idea that the current prices would continue (Nerlove 1958a; Akerman 1957). Nerlove (1958a; 1958b) contradicted this idea and asserted that expectations was based on so-called *adaptive expectations* that depend on the expected "normal" prices, which are formed on historical prices as well as the current prices. Further, Muth (1961) formed the *rational expectations theory*, which states that agents' expectations may be wrong, but are correct on average over time; that is, they will be wrong only because of non-systematic errors. See Nerlove and Bessler (2001) for a discussion on how expectations are formed and could be estimated; this includes other theories about expectations such as the quasi-rational expectations proposed by Nerlove and Fornari (1998).

Supply function of the competitive firm, which analytically is the partial derivative of the profit function with respect to price, has been seen as an entity by itself (Mundlak 2001). The way in which prices determine output has been the central theme in supply analysis, and thus supply analyses have been concerned with policy issues. Supply is defined as the quantity of a product that is offered for sale in a particular market during a specific time interval at any specified price. This means that supply is *planned* supply and not necessarily what is actually sold, which means that unprocessed products could be taken to mean the amount of products offered (Colman 1983). In other words, agricultural supply is not solely what is harvested but also what is under production or in stock. In that respect, Jarvis (1974) pointed out that a farmer sees the breeding herd as both an investment and an output, and this could produce unusual supply responses and dynamics. The explanation is that, when there is an increase in price that is expected to last, the farmers retain the young stock leading to an immediate reduction in output (Rosen, Murphy, and Scheinkman 1994; Sarmiento and Allen 2000). Colman (1983) reviews a number of different methods to estimate supply and concludes that no model is more favourable than others. In line with Keynes, he argues that the choice of model should depend on the research question, availability of data, and the amount of other resources available, such as personnel and time. Hence, the estimation of supply responses have been using different methods depending on data availability and the purpose of the study. When faced with cross-sectional or disaggregated data, the estimation of profit functions or cost functions have been the most popular (Mundlak 2001). The partial derivative of the profit function would give the supply function of the firm, while the factor demand of a firm is derived from the cost function. When aggregated time series are available, dynamic supply functions are mostly used. In that respect, Nerlove's (1956, 1958b) partial adjustment model nested together with adaptive expectations seem to be most influential (Askari and Cummings 1977). According to Mundlak (2001), the main findings of the supply analysis reported in the literature are thus: 1) the estimated elasticities decrease with the level of aggregation, and higher values are obtained for individual products than for aggregated output. 2) Indirect estimation of the supply elasticity, gained through the estimation of factor demand, resulted in larger values than those obtained by direct estimation. 3) The supply elasticity was higher during periods of increasing prices, and the rate of adjustment is higher during periods of increasing prices.

Numerous factors influence the production of an agricultural product. Factors that are controlled by the management, such as the amount of input, the quality level of input, and what technology to be used, will differ among firms. The appearance of firm heterogeneity means there will be variations among firms regarding how efficiently they allocate their resources to maximize profit, which means that the productivity progress will be different for each firm. In productivity studies, the necessary assumption is that there is a variation among producers, and not all producers are able to optimize production. Hence, measuring and analysing the productivity for an industry as a whole as well as among firms has caught a lot of attention in the literature, and a sophisticated methodological framework has been developed to analyse the impact of technical change on firm behaviour. Kumbhakar and Lovell (2000) provide a good overview of the parametric part of this tool kit, whereas Coelli et al. (2005) provide a review of index approaches. Although productivity and supply are two different concepts, productivity growth is a major factor in long-run levels of supply. While different management regimes cause different levels of efficiency and the ability to impose new technology across firms, exogenous factors such as weather conditions will affect a company’s productivity, since there is a close relationship between productivity and weather conditions. Shifting weather conditions that agricultural producers face between years and between regions will lead to shifting productivity levels across producers from year to year and between regions.

Supply analysis are continuously developing and, as such, are becoming more sophisticated, but methodological difficulties still remain. Price expectations, which affect the investment decisions, firm heterogeneity and appearance of economic inertia, progress in productivity due to technological change, both in the output and input production as well as due to the fact that changes in quality in both input and output factors are all elements that complicate the execution of supply analysis. Although the tool kit is rich, the complex nature of supply means that no simple solution exists.

2.2 Demand

Following Schultz's (1956) argument about the relative stability of "tastes" compared to "technology", it would appear that it is easier to enable demand analysis than supply analysis. Although the question of whether tastes are stable has produced an intriguing debate (Pollak 1970; Pollak 1978; Stigler and Becker 1977), the assumption of relatively stable tastes are still fundamental in most demand analyses.

Faced with a limited budget, standard demand theory assumes that a consumer will always choose the bundle of goods that is maximizing its utility. We further assume that a unique bundle of goods exists that maximizes a consumer's utility at every price and budget situation. This is what we call the *Marshallian demand function.* We assume that the representative consumer faces a linear budget constraint and its preferences are *rational, continuous, non-satiated,* and *strictly convex*. Furthermore, we assume that this consumer has perfect information, and prices are linear in quantity and exogenously given to the consumer. The linear budget constraint implies homogeneity of degree zero in prices and expenditures; in other words, the absence of money illusion. Non-satiated, or unsatisfied, preferences make sure that the consumer spends the entire budget (or income). This means that a change in price of one good will not affect the total expenditure, but a change in income will lead to an identical change in total expenditure.

Because the number of commodities that the consumers face is extensive, some level of aggregation across commodities is carried out in empirical demand analysis. The first set of commodity aggregates were carried out by Hicks (1936) and Leontief (1936), who proclaim that, if a group of prices moves in parallel, then the corresponding group of commodities can be treated as a single good. This is known as the *Composite Commodity Theorem*. However, prices of different goods are likely to move in the same way over time, which may lead to small differences between correct and incorrect price indices (Lewbel 1996). Another method is the use of *separability* of preferences, which assumes that commodities can be divided into groups so that preferences within a group can be described separate from the quantities from other groups (Deaton and Muellbauer 1980a). For example, if clothing is a group, the consumer can rank different clothing bundles, which is independent of his consumption of everything else outside the clothing group. This implies that the consumers are following a two-stage budget process. In the first stage, consumers allocate their total expenditures to broad groups of commodities, and in the second stage, group expenditures are allocated to individual commodities. However, problems with testing for separability and the development of integration and cointegration techniques has reinvented the use of the Composite Commodity Theorem by using the technique developed by Lewbel (1996).

There exist various methods to estimate demand for commodities. The easiest methods are single-equation models that are in linear, logarithmic, or double-log form. They are easy to estimate and interpret, but only the homogeneity restriction has an immediate consequence for single-equation models. Alternatively, in complete systems of demand models, the theory becomes more relevant since *homogeneity, monotonicity* (non-satiation assumption is fulfilled), *adding-up* (the budget constraint is satisfied), *symmetry* (consumers' consistency of choice), and *negativity* (utility is maximized) restrictions are directly imposed (or able to test empirically). The most common approaches of estimating demand systems seem to be the Rotterdam Model (Barten 1964; Theil 1965) and the Almost Ideal Demand System (AIDS; Deaton and Muellbauer 1980b). Several versions of those two models exist (see e.g. Barnett and Seck (2008), and the references therein) as well as hybrid versions of Rotterdam and AIDS, such as the CBS model (Keller and van Driel 1985) and the NBR model (Neves 1994).

During the last three decades, there has been enormous growth in applied demand studies. The literature shows that the procedures become more sophisticated over time due to increased knowledge as well as increased computing power. Still, many results have been, and still are, conflicting with theoretical assumptions about the rational consumer. Cozzarin and Gilmour (1998) surveyed a total of 129 articles and found that when homogeneity was tested, it was rejected 43 percent of the time (16/37), monotonicity was rejected 50 percent of the time (23/46), negativity was rejected 53 percent of the time (27/51), and symmetry was rejected 49 percent of the time (23/47). Still, Anderson and Blundell (1982, 1983) show that homogeneity and symmetry restrictions are not rejected in the long run in dynamic models. Deaton and Muellbauer (1980a) point out that theoretical restrictions do not always hold in empirical studies due to data or model characteristics, and, in that respect, Barnett and Seck (2008) show that many variants of AIDS and Rotterdam models do not perform well and do not yield satisfactory results. Still, Stigler (1939) argued that the gap between theoretical and statistical demand curves will probably never be completely bridged, and this seems to remain the case today.

2.3 Demand Growth

Since demand is a relationship between quantity and price, demand growth will only occur when there is a shift in the demand curve, which creates a new schedule of price and quantity relationship. The direct economic reasons for demand growth are changes in income and in the prices of substitute or complementary products, but indirect economic reasons can also be present. Demand can be affected by changes in demographics such as older, more educated consumers (Tomek 1985); changes in socioeconomic factors such as income distribution (Brown and Deaton 1972); the appearance of new product information (Tomek 1985); changes in product attributes such as product forms and quality (Ladd and Suvannunt 1976); or the accumulation of consumption capital (Stigler and Becker 1977).

Stone (1945) suggests using time trends, either linear, quadratic, or sigmoid, to allow for systematic variations in demand of those reasons mentioned above. Barten (1967, 1969) followed this approach and introduced a constant term in the Rotterdam system to allow for gradual changes in preferences. Deaton and Muellbauer (1980b) suggest using time trends in the occurrence of rejected homogeneity, since the occurrence of arbitrary time trends removes much of the conflict between data and theory. Furthermore, they suggest systematically modeling influences, such as price expectations and storage effects, other than the current total expenditure and current prices, in order to explain patterns in demand in a theoretically coherent and empirically robust way. Kinnucan et al. (1997) measures shifts in demand due to marketing expenditures, health information, and media coverage using aggregated indices. Piggott and Marsh (2004) also use an index approach based on the frequency of newspaper articles with unfavorable food safety information about beef, pork, and poultry products. Both time trends and indices can provide valuable insight into how demand changes if such shifts vary systematically. However, the multitude of effects on demand suggests that demand growth is complex for any product and there is no *a priori* reason to expect demand growth to be smooth over time.

Demand shifts due to indirect economic reasons are often referred to as a *structural change*, and several methods exist to detect structural change (see e.g. Maddala and Kim (1998) chpt. 13-16). Several studies have investigated whether changes in consumption patterns are caused by structural changes in demand (e.g. Chalfant and Alston 1988; Eales and Unnevehr 1988; Eales and Unnevehr 1993; Moschini and Meilke 1989; Moschini 1991; Choi and Sosin 1990; Chavas 1983; Davis 1997). However, testing for structural change is not an easy task. The rejection of the homogeneity or symmetry assumptions, or the appearance of a significant unexplained trend, have been interpreted as indications that tastes have changed over time (Chalfant and Alston 1988). The findings of structural change are just as likely to be caused by using an incorrect functional form, since any parametric test for structural change in demand analysis depends on a joint hypothesis of the functional form and other underlying assumption of the specified model (Alston and Chalfant 1991a; Alston and Chalfant 1991b; Chalfant and Alston 1988).

Any shift in price and/or quantities reflects the occurrence of any of the following events: 1) a movement along the original demand slope due to a shift in supply; 2) a shift in demand caused by changes in relative prices or expenditures; or 3) a shift in demand caused by other factors (a structural change in demand) or a combination of any of these factors (Brækkan 2014a). Taylor and Taylor (1993) split instances of demand growth for interstate telephone calls into explained and unexplained growth. The explained growth is due to changes in prices, income, and population growth, while the latter is the residual measured elements due to other factors not explained by the model. The total shift in demand is then the sum of the explained and unexplained part. Marsh (2003) offers an alternative approach to measuring the total changes in demand. This approach allows demand to vary independently between years. Given a specified elasticity of demand, the approach measures the difference between actual price change and the expected price change under the assumption of no demand shift from the previous period. A demand shift as specified by Marsh includes the shift in demand by all factors affecting it, both known and unknown, which can be interpreted as a gross shift in demand.

2.4 Markets

When analyzing the supply and demand, an appropriate understanding of the market in question is required. Markets can be defined both in geographical space as well as in product space. A market can be defined as follows:

> *"an article capable of transportation must flow from the market where its value is less to the market where its value is greater, until the difference in*

value, from one market to another, represents no more than the cost of transportation" (Cournot 1897, p. 131).

Both the Composite Commodity Theorem and the Law of One Price are important in market analysis, since they address the issue of defining a market in geographical and product spaces. The Composite Commodity Theorem states, as mentioned before, that prices of several goods that move together can be treated as a single good. The Law of One Price is derived from the assumption that no arbitrage possibilities exist and that identical goods in a market must have identical prices, only adjusted for transportation costs. When the Law of One Price holds for a group of prices in different locations, they move proportionally to each other over time, and the markets for the group are integrated.

3. Salmon aquaculture

Over the last few decades, aquaculture has been the fastest growing animal-based food production technology (FAO 2012; Smith et al. 2010), and salmon production has grown faster than aquaculture production in aggregate. Farmed salmon production, which includes Atlantic salmon, coho, and salmon trout, has increased from a few thousand tons in 1980 to over 2.4 million tons in 2011 (Asche et al. 2013). Atlantic salmon is the dominant specie, accounting for more than ¾ of the worldwide output of farmed salmon. Norway is the world's leading producer with a 51% share of the total production in 2009 (Larsen and Asche 2011), and as much as 68% share of the total production in 2010 due to disease outbreaks in Chile (Larsen 2011). Two key factors make this production growth profitable. First; a significant productivity growth has reduced real production cost to less than 33% of the cost level of the 1980s (Asche 2008; Tveterås 1999; Guttormsen 2002; Kumbhakar and Tveterås 2003; Asche, Roll, and Tveterås 2009; Nilsen 2010; Roll 2012). Second; advertising, product development, and improved logistics have increased demand (Bjørndal, Salvanes, and Gordon 1994; Asche 1996; Kinnucan et al. 2003; Kinnucan and Myrland 2005; Kinnucan and Myrland 2008; Xie, Kinnucan, and Myrland 2009; Larsen and Asche 2011; Asche and Bjørndal 2011). Since 2000, both salmon prices and volatility have increased (Øglend 2013; Øglend and Sikveland 2008; Solibakke 2012). Recent studies suggest that productivity growth has slowed down, and the increasing volumes suggest that demand has outpaced supply growth (Asche, Guttormsen, and Nielsen 2013; Vassdal and Sørensen Holst 2011; Brækkan 2014b).

The increase in salmon production in the last decades is due to productivity growth through improved technologies and better production practices. This increased control in the production process has reduced production costs tremendously. In 2008, production costs were only 28% of what they were in 1985, and the sales price was only 30% of what it was in 1985 (Asche and Bjørndal 2011). This is an indication that the salmon industry is a competitive industry, since reductions in production costs cause reductions in sales prices.

3.1 Production and Supply of salmon

There exists a vast body of literature about different aspects of the production process in farmed salmon, and as Norway is the only producing country where data are systematically gathered, practically all studies have used Norwegian data. Guttormsen (2002) characterizes the structure of the industry through inspecting the elasticity of substitution and scale, and

Tveterås (2002) and Tveterås and Battese (2006) investigate the agglomeration of the industry and its externalities. Several studies analyse the risk involved and the variations in profit levels (Tveterås 1999, 2000; Asche and Tveterås 1999; Kumbhakar and Tveterås 2003).

Productivity and efficiency studies have also caught a lot of attention in the literature. Asche, Bjørndal, and Sissener (2003) and Asche (1997) discuss productivity growth in the salmon industry and the development of production shares among the production countries. Vassdal and Sørensen Holst (2011) and Asche, Guttormsen, and Nielsen (2013) determine the total factor productivity in the industry during recent decades. Nilsen (2010) analyses the existence of learning-by-doing or technological leapfrogging with respect to technical efficiency in the industry, and Asche et al. (2013) analyse the effect farm size and company size have on the development of productivity growth. The literature shows that, due to technological progress, which in turn increase the control of the production process, has led to productivity growth and the lowering of production costs (Roll 2012). This has further led to an improvement in the technical efficiency for salmon farmers over time, and the inefficiency that is still present is mainly due to temporary shocks (Asche and Roll 2013).

Somewhat surprisingly, with all these production studies, there have been few attempts to estimate supply elasticity in the literature. Only three studies have reported such estimates: Asche, Kumbhakar, and Tveterås (2007); Andersen, Roll, and Tveterås (2008); and Aasheim et al. (2011).

Asche, Kumbhakar, and Tveterås (2007) use a panel data set with Norwegian fish farms with annual observations for the period of 1985 to 1995 to estimate a cost function, which is common with most of the productivity studies. They employ the fact that a cost function is a special form of a restricted profit function. They report a long-run supply elasticity of 1.5.

Andersen, Roll, and Tveterås (2008) also use a panel data set with Norwegian fish farms with annual observations from 1985 to 2004 to estimate a profit function and then deviate from earlier productivity studies. They estimate a partial equilibrium model, where in the short run capital is fixed and in the long run it is variable. Given the enormous increase in the size of the farms, the restriction put on the farmers in the short run is much stronger. This is also reflected in the short-run elasticity, as this is barely positive at 0.05, indicating very limited short-run response. The long-run elasticity is very similar to the other study and is reported to be 1.4.

Aasheim et al. (2011) use an aggregated data set with monthly observations from January 1995 to December 2007. Using a system of equations, their study shows how biomass development affects short-run supply, and they find a short-run supply elasticity of 0.09, which is in line with the study by Andersen, Roll, and Tveterås (2008). However, their long-run elasticity is reported to be 0.13, which differs conceptually from the results from Asche, Kumbhakar, and Tveterås (2007) and Andersen, Roll, and Tveterås (2008).

Although technological improvement in the salmon industry has increased the control over the production process, there are still external factors that affect the production of farmed salmon, and sea temperature seems to be the most important external factor that affects the production over which the producers have little control. Lorentzen (2008) shows that the grow-out period differs between the northern and southern parts of Norway, using experimental data, due to different temperature regimes. Hermansen and Heen (2012) show in a scenario of linear temperatures increase of 1°C from 2008 to 2030, ignoring the effect of technology, would lead to a productivity increase in the north and a decrease in the south, and there would be more or less status quo in the central region of Norway. Aasheim et al. (2011) show that sea temperature influences the growth rate of salmon, but that it has no effect on the short-run supply. Since there is a close relationship between sea temperature and productivity, variations in sea temperature may be the reasons for inefficiency that is present due to temporary shocks, the over- and under supply of salmon which again may cause fluctuating prices and variations in profit levels.

3.2 Salmon demand

In recent decades, there have been tremendous research on demand for salmon. Studies have found substantial variations in the estimated elasticities of demand for salmon. Studies using datasets from the 1990s and earlier have typically found that the demand for salmon is elastic (Asche, Bjørndal, and Salvanes 1998; Asche, Bremnes, and Wessells 1999; Asche, Salvanes, and Steen 1997; DeVoretz and Salvanes 1993). Asche (1996) showed that demand becomes less elastic as production increases. Reported elasticity values of the recent literature, using data from 1990s to 2010, has reported elasticity values both in inelastic and elastic ranges from -0.2 to -1.7 (Aasheim et al. 2011; Chidmi, Hanson, and Nguyen 2012; Fousekis and Revell 2004; Hong and Duc 2009; Jones, Wozniak, and Walters 2013; Muhammad and Jones 2011; Sakai et al. 2009; Singh, Dey, and Surathkal 2012; Tiffin and Arnoult 2010; Xie, Kinnucan, and Myrland 2009; Xie and Myrland 2011). There are variations in the reported elasticity values for different product forms, markets, and methodologies.

In the period before 2000, the decreasing prices and increasing quantities may solely be due to supply expansion, although this does not mean that demand remained constant throughout, and Bjørndal, Salvanes, and Andreassen (1992) indicate that generic advertising has led to an outward shift in demand. In a series of studies, Kinnucan and Myrland (2000, 2002, 2003) investigate the effects of generic advertising in an EDM framework. Although significant, the effects are found to be tiny compared to own-price and income effects. Since 2000, however, the growth in quantities at non-decreasing prices clearly indicates expanded demand. Several studies have found evidence of demand growth using trend indicators such as advertising or time trends (Myrland et al. 2004; Xie, Kinnucan, and Myrland 2009; Xie and Myrland 2011). Asche et al. (2011) find that the gross demand growth in the EU and France have been substantial, using data from 1996 to 2008, with average demand growth on 7.6 and 4.7 respectively from year to year.

3.3 A global salmon market

When analyzing a market, one must establish the boundaries of the market, and a market for an aggregated product requires that Law of One Price and the Composite Commodity Theorem holds. The limits of the market exist in geographical space, so we must determine if products that are sold in different locations are considered to be in the same market, and in product space, we must determine if different salmon products constitute the same market. Farmed salmon is a globally traded commodity sold in many different product forms, and extensive empirical analysis has investigated this subject.

Several studies show that the salmon market is a separate market from other wild fish (Gordon, Salvanes, and Atkins 1993; Asche, Bjørndal, and Young 2001; Asche, Jaffry, and Hartmann 2007; Nielsen, Smit, and Guillen 2009; Jaffry et al. 2000). There appears to be one global market for salmon, which includes both farmed as well as wild salmon (Asche, Bremnes, and Wessells 1999; Asche et al. 2005; Asche 2001).

Asche and Guttormsen (2002) show that, although there are seasonal variations in the prices for different weight classes of salmon, their prices are also highly related. All of these studies indicate that there is a highly integrated market for salmon both globally and for different product forms. Still, in a recent study, Xie and Myrland (2011) find that wild salmon constitute a different market niche from farmed salmon, but this does not necessarily imply that wild salmon are not in the same market as farmed salmon. Each product form or species does not need to be directly substitutable with any other. Still, so many species and product forms are substitutable in the salmon market that the price formation process is closely connected.

4. Summary of the papers in this dissertation

This dissertation consists of four papers, all focusing on the farmed salmon industry. The first two papers focus on the production and supply side of the farmed salmon market, and the latter two focus on the demand side of the farmed salmon market. The first paper determines the importance of temperature in the growth of Norwegian farmed salmon for three different regions. Here we estimate a growth function with aggregated data using sea temperature as the explanatory factor. Existing studies on salmon growth mainly rely on experimental data or data from only a single or several fish farms, and, as far as I know, no other studies have examined how variations in biophysical conditions affect growth from year to year.

The second paper determines supply and harvest response of Norwegian salmon farmers from three different regions in Norway. In the farmed salmon literature, only three other studies have reported supply elasticities. Existing studies have used a panel data approach with yearly data, or focused on short-run supply. In this study short- and long run elasticities are estimated using monthly data.

The third paper uses the approach by Marsh (2003) to determine annual relative shifts in demand for different salmon-consuming regions globally. This approach allows demand to vary independently between years and avoid restrictions that require smooth demand growth over time.

The fourth paper extends the procedure of the third. We decompose the total demand shifts into three parts: the impact of changes in substitute prices, income, and the residual demand shift due to other factors.

4.1 Summary of Paper 1: The Importance of Temperature in Farmed Salmon Growth: Regional Growth Functions for Norwegian Farmed Salmon

The range of environmental and biological conditions along the Norwegian coast suggests that the growth of farmed salmon will differ from one region to another. We estimate a logistic growth curve for three different regions in Norway to determine how temperature affects the growth of farmed salmon. Although the growth rates of an individual salmon depend on several factors, such as the amount of feed, light conditions, and sea temperature, we have chosen to focus only on sea temperature to explain growth. The results show that sea temperature is a critical factor to explain growth. Periods with higher sea temperatures lead to faster growth in the North and Central regions, while leading to slower growth in the South. The opposite occurs during periods with relative low sea temperatures, leading to faster growth in the South region and slower growth in the North and Central regions. Efficient salmon growth was previously believed to be best promoted at water temperatures between 13-17°C. However, a recent study by Hevrøy et al. (2013) shows that growth is better achieved in lower temperatures, and the comfort zone should be somewhere around or below 13°C; this study shows similar results. Still, when temperature is below that range, slower growth occurs. The study indicates that the grow-out period is longer in the South region compared to the North and Central regions. However, it is not accurate to assume that these regions are equivalent, since there are differences in the behavior between regions. The South region releases more of its juveniles in the autumn release and thus harvests a larger share of their fish later in the cohort's lifetime. Further research is necessary to verify whether these findings will hold for an individual fish. Still, this study indicates that, in a situation with higher sea temperatures, more efficient growth will occur in the Central and North regions, with the absence of technology improvement, which is in line with the findings of Hermansen and Heen (2012). This study also indicates that further control in the production process, with letting the salmon spend a greater part of their lives in a controlled environment, may lead to further productivity growth for the industry.

4.2 Summary of Paper 2: Regional Supply Response of Norwegian Farmed Salmon

In academia, a strong attention have been on studies on demand and market structure, while studies of supply have not caught the same interest. Like in other sectors of the economy, the observed prices and quantity figures in the farmed salmon market indicate an interaction between supply and demand. This study attempts to estimate regional long-run and short-run supply elasticities for three different regions in Norway. Here we estimate a supply model in error-correction form, with the partial adjustment model nested within it, as proposed by Hallam and Zanoli (1993). We find that the salmon producers are responding to price changes in the long run, while there are limited responses to price changes in the short run. The long-run response differs from region to region, and the own-price supply elasticity is 1.22 for the Northern region, 1.39 for the Central region, and 0.58 for the Southern region, with an national average of 1.06. This indicates that the Northern and Central regions are more able to respond to price changes that occur in the market than in the Southern region. One reason for this might be that the Southern region is more tied up due to biophysical constraints such as sea temperature, and periods with high sea temperature may force the farmers in Southern

Norway to a higher degree to slaughter their fish independent of the price, in contrast to farmers in the Central and Northern regions of Norway.

4.3 Summary of Paper 3: The Bumpy Road of Demand Growth – An Application to Atlantic Salmon

Since 2000, salmon prices have been volatile and slightly increasing (Øglend 2013; Øglend and Sikveland 2008). During this period, the markets have expanded both geographically and with an increased variety of product forms. At increasing volumes, this suggests that demand growth has been outpacing supply growth. These recent developments encourage further investigation of demand in different salmon-consuming regions. As salmon is a globally traded commodity, it is an ideal product for measuring demand growth in all major importing regions. In this paper we use an adjusted procedure of Marsh's (2003) approach for measuring demand shifts. We define a shift in demand as the percentage shift in quantity demanded at a given price. Asche et al. (2011) applied Marsh’s procedure to the EU and France; we extend it to all major salmon-importing regions of the world in the period between 2002 and 2011. We also perform a sensitivity analysis to examine the impact of the choice of elasticity parameters on the computed demand shifts. The results show substantial variations in demand growth, both between regions and over time. Emerging markets, such as Russia and Brazil, exhibit the highest growth in the demand for salmon, with average annual increases of approximately 20 percent. The U.S. and Japan have the lowest growth in demand, with an average of about three percent per year. Total global demand growth from 2002 to 2011 was approximately 94 percent, or around eight percent per year. Furthermore, demand does not grow smoothly. There were several periods of negative demand growth in every region examined. While the inclusion of a time trend in a demand analysis would be able to capture long-run trends, the year-on-year variation in demand is so large that a trend variable would not be able to explain or predict a short-term shift in demand. The sensitivity analysis confirms overall patterns. We perform 10,000 simulations using different values for elasticities of demand and recalculate the demand shifts for each simulation. The results indicate that levels of demand growth in Brazil and in the EU are the most uncertain. The 5 and 95 percentiles for average annual demand growth are 13.5 and 25 for Brazil and 3 and 11.7 for EU, respectively. The percentiles for the average global growth are 6 and 10 percent. In other words, global demand growth for salmon has been in the region between 6 and 10 percent annually from 2002 to 2011.

4.4 Summary of Paper 4: The Demands They Are a-Changin'

This paper extends the procedure of Paper 3. We show that, when data and appropriate elasticity values are available, we can decompose the gross shift in demand between the impact of specific variables and the residual demand shift caused by unaccounted-for variables. This approach still permits demand to vary independently between periods while quantifying the impacts of any variable of interest where data are available. By disentangling the impact of direct economic factors, like changes in relative prices and income, the impact of indirect economic factors are determined. This provides an alternative to the use of trend indicators for measuring demand shifts caused by such factors. We apply this procedure to all major salmon-importing regions from 2002 to 2011. The results indicate, as in the third paper, a substantial variation in demand growth both over time and between regions. The average residual shift in demand accounts for more than half of the total demand shift in every region except Russia. This suggests that changes in income and relative prices account for less than half of the recent growth in salmon demand. The standard errors of the residual demand shifts are large for all regions. This indicates that unexplained shifts in demand are unsystematic; hence, using time trends to capture unexplained demand shifts is inappropriate for explaining year-on-year shifts. The large residual demand growth and standard errors suggest that further research is necessary to understand the reasons behind the development of the demand for salmon. The results also demonstrate that any demand analysis focusing only on relative prices, income, and a trend variable will not appropriately account for the large variation in salmon demand in any region.

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