BENEFITS FROM R&D AND SPILL-OVERS IN AQUACULTURE: AN EU-15 MODELLING APPROACH

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ABSTRACT

Aquaculture is increasingly important for the future supply of fish because of steadily increasing demand while supply from fisheries is stagnating. In the EU aquaculture production has grown strongly in some countries, such as Spain and Greece, but was flat at a low level in others, such as in Germany, where national aquaculture production contributes only little to total supply of fish for food. Despite the small size of their aquaculture industries some German states have initiated sizeable aquaculture R&D-programs with the objective to foster local aquaculture industries. This study analyses economic effects of aquaculture R&D from the perspective of a country whose aquaculture industry is small in relation to the EU market and which has to consider significant R&D-spill-overs in addition to the usual impacts of R&D on producers' costs and consumers' consumption expenses. Based on fish market characteristics for EU-15-countries three scenarios are investigated using IFPRI´s Dynamic Research Evaluation for Management (DREAM) model. In the first scenario R&D-effects only take place in German aquaculture production and no spill-overs to other countries occur. The second scenario allows for spill-overs of technologies from Germany to all other EU-15-countries. Time lags for the transmission of technologies to the remaining EU-15-countries are introduced in the third scenario. DREAM computes the effects of R&D for producers and consumers: changes in quantities and prices of fish from aquaculture leads to changes in producer and consumer surplus. The results of this paper provide important implications for political decisions concerning the allocation of public funds for R&D-projects in aquaculture.

Keywords: Aquaculture, R&D, economics, research benefits, DREAM

INTRODUCTION

Fish is an important source of protein for human consumption and population growth combined with growing personal incomes have resulted in a significant increase in world demand for fish for food. Worldwide supply of fish from capture fisheries is, however, unable to keep pace with increasing demand and, as our oceans become increasingly depleted, the gap is closed with fish from aquaculture. The rise of this industry was, and still is, spectacular. With an annual growth rate of nearly 7 % in the last quarter century, aquaculture has become the fastest growing food production industry in the world (FAO 2009a) and currently aquaculture contributes about half of the world's food fish for human consumption (FAO 2009a). Europe´s contribution to worldwide aquaculture production is small: only 4 % of worldwide aquaculture production quantity comes from Europe. Moreover, aquaculture production growth in Europe has slowed to about 1 % per year since 2000 (FAO 2009a).

The production of fish from capture fisheries and aquaculture in EU-15 has fluctuated between 6 and 7 mio. t in the years from 1965 to 1998. Since then, finfish production nosedived and accounted for 4.4 mio. t in 2007 (FAO 2008). Contrary to production, EU-15 consumption of fish increased between 1961 and 2005 from roughly 4.8 mio. t to 7.2 mio. t, which is a rise of roundabout 50 % of the consumption in 1961. The consumption per capita and year increased in the same time from 15.1 kg to 18.7 kg (FAO 2008). In consequence, Europe is the world's largest importer of fish (FAO 2009a; EU 2009).

The European Commission wants to decrease fish imports into the European Union (EU) by stimulating domestic production (EU 2009). One way to do this is to devote more productive resources to aquaculture – more fish per production unit, more fish cages in the seas, or more fish tanks or ponds on land. The potential gains from this strategy are limited. Maximum stocking densities are quickly reached and industry experts warn, that available resources of water and land area are becoming increasingly scarce and often have superior alternative uses (HILGE and HANEL 2008; EU 2009). An alternative to a resource-based growth strategy for encouraging aquaculture production is to shift the aquaculture production frontier by means of R&D. Aquaculture inventions that result from R&D may become widely adopted, shifting the aquaculture production frontier upwards and the supply curve downwards, increase quantities of aquaculture fish produced, and reduce market prices for fish. Moreover, the outputs of R&D, mainly new knowledge and inventions, tend to encourage the discovery of even more new knowledge and inventions and a path-dependent, recursive invention process may emerge in aquaculture (ARTHUR 2009).

The EU has chosen the R&D-strategy for stimulating domestic production and has invested heavily in aquaculture R&D. During the 6th Research Framework Programme (2002–2006) R&D related to aquaculture attracted close to € 100 mio. and the EU Commission regards the continued support for aquaculture R&D as essential for the development of aquaculture (EU 2009).

In Germany, domestic aquaculture production contributes only little to total supply of fish. Even though their aquaculture production is currently low, some states in Germany, such as Schleswig-Holstein, have launched sizeable aquaculture R&D projects that are co-funded by the EU. Such projects tend to be justified by a wide range of politically attractive goals and their economic impact may not be the most important consideration for their promoters and funding agencies. Analyzing the likely economic impact is nevertheless an important and challenging task for R&D-economists. The goal of this paper is to analyze the EU-wide economic impact of aquaculture R&D conducted by a single EU country which is a small aquaculture producer. Such an analysis has to take into account R&D spillover effects in addition to domestic R&D impacts.

In particular, EU-15 market characteristics are used to explore three scenarios to measure the effects of German aquaculture R&D on producer and consumer surplus. The first scenario shows the effects of R&D if technologies can only be adopted by German aquaculture producers. The second scenario allows for technology spillovers and in the third scenario time lags for the spillovers are introduced additionally.

We proceed as follows. After this introduction the next section highlights the significance of R&D for the development of aquaculture. Then we recall the basic economic theory for assessing R&D impacts followed by a briefly introduction of IFPRI's DREAM modeling software (Dynamic Research Evaluation for Management) (ALSTON et al. 1995; WOOD et al. 2000) which we use for estimating the welfare effects. In this section we also report our data sources and the parameters we used in DREAM-runs. In *ex ante* technology assessment the future usually is represented by distinct scenarios and we develop three scenarios. Results from DREAM-runs are reported and discussed before the paper is closed with remarks.

SIGNIFICANCE OF R&D FOR THE DEVELOPMENT OF AQUACULTURE

If the number of scientific publications is an indicator of R&D activity in any one field, then aquaculture and fisheries R&D must have grown significantly over the past decade. In the period 1990-1994 ISI's Science Citation Index reported 1,751 publications related to aquaculture and fisheries; ten years later the number had grown to 8.634 publications in the period 2000-2005 (SEIDEL-LASS 2009).

Fish are the youngest domesticated animals and aquaculture R&D is relatively young compared to R&D on poultry, pigs, or cattle. This suggests that the returns to research, measured in terms of new knowledge published in research papers and useful inventions, may still be large. But there are also causes for diminished R&D productivity in aquaculture. In contrast to animal science research, which tends to be strongly focused on a small number of species and breeds, aquaculture R&D is concerned with several aquatic life-forms, including a wide range of fish species. We do not know the exact number of fish species that are farmed in Europe but it is easy to draw up a list of ten commercially important species, each with its own demands on feed and management, as well as its specific heritabilities for desirable traits. Moreover, aquaculture production systems vary considerably from technologically undemanding, natural-resource-intensive pond systems to technologically sophisticated, capital-intensive recirculation systems where fish are kept in tanks under closely controlled conditions. This implies that aquaculture R&D, which is still comparatively small in size, is nevertheless highly diversified, and perhaps even fragmented, because nearly each fish species needs and each production system has its specific R&D requirements. Moreover, the scope is limited for transferring R&D results from one fish species to another, and from one production system to another.

If aquaculture R&D is focused on a single species and on one production system, as it was the case in Norway's R&D on salmon in cage systems, progress can be impressive. Mostly as a result of R&D, production cost of the Norwegian salmon industry fell by nearly 70 % in the period from 1982 to 1997 (ASCHE et al. 1999; ASCHE 1997). An important source of productivity growth were, and still are, public R&D investments of which several inventions, e.g. progress in selective breeding and feeding, have been quickly embraced by salmon producers in Norway (GUTTORMSEN 2002).

An important economic rationale for Norway's salmon-R&D was to obtain a competitive advantage in salmon production. New knowledge and inventions do, however, easily spill over to producers elsewhere and salmon producers in other countries have been able to adopt Norwegian technologies. In this way, Norwegian governments spending on salmon-R&D produced a positive externality for foreign salmon producers and probably for foreign consumers as well (TVETERÅS and BJØRNDAL 2001). Furthermore, the results of Norwegian R&D have not only spilled over into other countries, they have also spilled over to other species. In particular, aquaculture producers in the Mediterranean have appropriated some technologies from Norway to boost their own production of sea bream and sea bass.

BASIC ECONOMICS OF R&D IMPACT

This section briefly revisits a graphical representation of a standard economic model of R&D impact. (The corresponding analytical model can be found in the appendix). The model ignores many of the potential dynamic impacts of R&D. Limited empirical data advised us, however, against employing more detailed and sophisticated models. Moreover, the economic model that we present here is the basis for the DREAM-software that we use in our numerical analysis of three R&D-scenarios.

For the evaluation of R&D benefits, a commodity market model with linear supply and demand is used. R&D is assumed to lead to a parallel downward shift of the supply curve, which is shown in figure 1. S_0 represents the initial supply of the product and the demand curve is given by D. The initial market equilibrium is given by price P_0 and quantity Q_0.

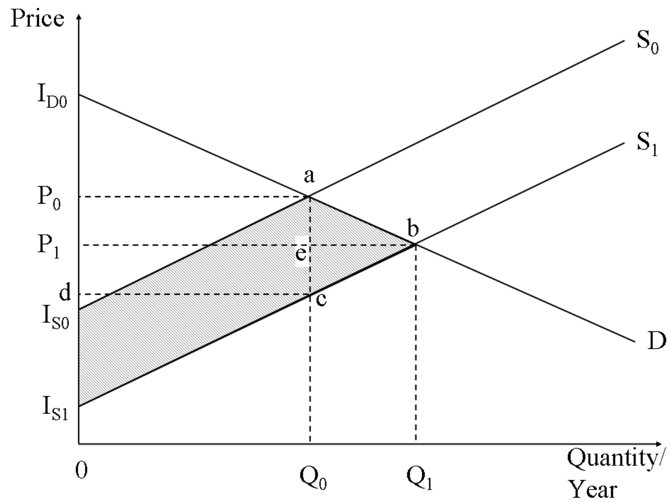
Suppose that R&D results in yield-increasing or input-saving technologies. This can be expressed as a reduction in per unit production costs, k. In the graph, this is expressed as a parallel downward shift of the supply curve from S_0 to S_1. The demand curve D is unaffected by R&D and market equilibrium after the supply shift is given by P_1 and Q_1. Compared to the initial equilibrium (P_0, Q_0) the new equilibrium (P_1, Q_1) is characterized by a higher production and consumption volume, and a lower price.

The producer surplus after the supply shift is equal to the triangle P_1bI_{S1}. The change in producer surplus is shown by the area P_1bI_{S1} minus P_0aI_{S0}. The consumer surplus after the supply shift is equal to the area P_1bI_{D0} and its change corresponds to the area P_0abP_1. The total benefit from the R&D induced supply shift is equal to the shaded area beneath the demand curve D and the supply curves S_0 and S_1 (area $I_{S0}abI_{S1}$). Total benefits can be divided into two parts: The area $I_{S0}acI_{S1}$ is the cost saving on the original quantity Q_0. The area abc is the economic surplus due to the increment in production and consumption.

As the experience from Norway salmon-R&D has shown, R&D results of one country i may also be adopted by another country j. If country j´s producers adopt this new technology they are also able to benefit by lowering their production cost and thus shifting the supply curve downwards. The supply shift in country i at time t, $k_{i,t}$, is transferred to country j via a spillover coefficient θ_{ji}. The strength of j´s supply shift $k_{j,t}$ is determined by θ_{ji} and $k_{j,t}$ equals ($k_{i,t}\times\theta_{ji}$). The technology-adopting country j gains welfare benefits for producers and consumers and the graphic representation is equivalent to figure 1.

There was a long debate in the agricultural R&D literature on how to best represent the impact of R&D on supply – as a parallel or as pivotal shift. The choice is not trivial because it can significantly influence the magnitude and the distribution of estimated research benefits (ALSTON et al. 1995; Rose 1980). With parallel supply shifts, producers always benefit from research unless supply is perfectly elastic or demand is perfectly inelastic. In the case of a pivotal shift, in contrast, producers only benefit when demand is elastic (ALSTON et al. 1995). We follow the suggestion by ROSE (1980) and assume parallel shifts of supply. This has the additional advantage that we do not need to be concerned with the functional forms of supply and demand for fish (ALSTON et al. 1995).

Figure 1: Surplus distribution in the basic model of research benefits



Source: ALSTON et al. (1995)

DREAM AND DATA FOR ITS SPECIFICATION AND PARAMETERIZATION

This study focuses on the production and consumption of finfish from aquaculture in Europe. For reasons of data availability, we are only concerned with the EU-15-countries. In addition, our study does not consider possible effects on markets for substitutes or externalities.

DREAM is a software package that implements the linear model with parallel supply shifts presented above. DREAM has been used in several R&D impact studies, for example for coffee from Uganda (YOU and BOLWIG 2003; BENIN and YOU 2007), for agricultural crops in Australia (JONES et al. 2005) or to quantify the degree and scope of R&D spillovers for a set of key agricultural commodities in Eastern and Central Africa (OMAMO et al. 2006).

DREAM requires that markets always clear. This is ensured by introducing a virtual country, the "Rest of the World" (ROW) which meets excess demand from the EU, which is by far the largest single market for imported fish (FAO 2009a).

For each country the market of fish from aquaculture has to be defined for the first simulation period $t=0$. The markets are characterized by

- quantities of supply and demand;
- exogenous growth of supply and demand;
- elasticities of supply and demand;
- initial prices;
- supply shift parameter $k_{i,t}$, and
- technology spillover parameter θ_{ij}.

We obtained our data from several sources. Data on quantities and values of aquaculture production were obtained from FAO's Fishstat Plus database (FAO 2008). Initial market prices were calculated by dividing values by quantities.

Exogenous growth for EU-15 aquaculture production may be estimated in several ways. A simple was is to determine the growth in aquaculture farm area. The potential development of aquaculture depends, however, on a number of factors, such as market demand, feed supply, environmental constraints, and innovations (FAILLER 2007). DELGADO et al. (2003) projects an annual percentage growth rate (APR) of 2.1 % for EU-15 aquaculture production between 1998 and 2020. Additionally FAILLER (2007, 2008) predicts an APR of less than 0.7 % for EU-15 aquaculture production between 1998 and 2030. Aquaculture production data of finfish between the years 2000 and 2007 often show a slight decrease of production for EU-15-countries (FAO 2008). We assume that innovations enabled by aquaculture R&D are the only source of growth and that the exogenous growth rate for aquaculture supply is zero.

Data on the consumption of farmed finfish are unavailable. FAOSTAT (FAO 2009b) provides data on the food fish supply which can be equated with the consumption of fish. These data include fish from both capture fisheries and aquaculture. The share of fish from aquaculture increased steadily in the last years and FAO estimates this share to be 24 % in the year 2006 in the world excluding China (FAO 2009a). We adopt this estimate for our model runs.

FAILLER (2007, 2008) predicts that per capita fish consumption will slightly increase until 2030 for most EU-15-countries, with the exception of Ireland, Portugal, Spain, and Sweden. FAILLER´S (2007, 2008) projections on fish consumption are based on national trends but exclude economic factors like income growth. Much of the change in the level and structure of fish consumption reflects more subtle and complex demographic and behavioral variables. Ageing populations, changing gender roles, smaller household sizes, dietary concerns, food safety issues as well as ethical concerns are evident throughout Europe (EUROPEAN COMMISSION 1999). We are unable to account for these factors and we estimate exogenous consumption growth as the sum of the population growth rate and the income growth rate weighted by the income elasticity. Data for population and income growth are taken from OECD (2009) and we use the income elasticity for food and beverages from SEALE et al. (2003).

Further, elasticities for demand and supply of finfish from aquaculture have to be quantified. The review of studies on demand elasticities for fish by ASCHE et al. (2005) indicates that demand in most markets is price elastic but for some aquaculture species demand seems to become less elastic with increases in supply. A meta-analysis of price elasticities by GALLET (2010) showed a median price elasticity of -0.8 for fish. DELGADO et al. (2003) suggest that a reasonable range of own price elasticities is -0.8 and -1.5. We assume a demand elasticity of -1 and we explore the sensitivity of our results by parameterize demand elasticities in the range from -0.8 and -1.5.

We are unaware of studies that report empirical estimates of supply elasticities for EU-15 aquaculture production. DEY et al. (2004) estimated aquaculture supply elasticities between 0.28 and 1.24 for some developing Asian countries. For lack of better information, we use a supply elasticity of 1 in our model.

The impact of R&D on the supply curve has to be parameterized by estimating the R&D-induced reductions of production costs. ASCHE (1997) and GUTTORMSEN (2002) analyzed the production costs of the Norwegian salmon industry. Production costs in 1995 were only about a third (36 %) of the production costs in 1982. According to the two studies, rates of cost reduction were in the range from 7.1 percent to 7.6 percent per year. R&D in salmon aquaculture can be regarded as demanding compared to R&D for other fish species. Similar rates of cost reduction may therefore by feasible in EU-15 aquaculture. We assume a per unit cost reduction rate of 5 percent per year.

Table 1 summarized the base data used in DREAM simulations. Luxembourg is omitted from this table because for this country data on fish consumption and production are unavailable.

In the following section we use the Dynamic Research Evaluation for Management (DREAM) model of the International Food Policy Research Institute (IFPRI) to conduct a comparative welfare analysis of alternative scenarios.

Table 1: Base data for simulation: EU-15 market for finfish from aquaculture

Country	Supply	Demand	Price	Elasticity		exogenous growth of demand
	(1,000 t)	*(1,000 t)*	*(1,000 US$/t)*	Supply	Demand	(p.a. in %)
Austria	2.5	20.5	5.70	1.0	1.0	0.90
Belgium	0.2	42.7	4.18	1.0	1.0	1.11
Denmark	35.2	20.5	3.42	1.0	1.0	0.57
Finland	13.4	39.0	4.66	1.0	1.0	1.47
France	49.5	321.8	3.94	1.0	1.0	0.78
Germany	33.7	254.7	4.56	1.0	1.0	0.31
Greece	85.4	40.6	5.42	1.0	1.0	1.83
Ireland	13.1	15.0	5.62	1.0	1.0	2.39
Italy	51.7	207.9	5.14	1.0	1.0	0.06
Netherlands	9.7	70.8	5.60	1.0	1.0	0.74
Portugal	4.3	116.9	6.12	1.0	1.0	0.04
Spain	58.8	279.6	4.36	1.0	1.0	0.90
Sweden	4.9	47.4	4.55	1.0	1.0	1.38
UK	145.6	227.0	4.97	1.0	1.0	1.37
*ROW	1,196.2	-	4.79	1.0	-	-

Source: FAO (2008); FAO (2009b); OECD (2009); SEALE et al. (2003), own calculations

SCENARIO ANALYSIS

The objective of this scenario analysis is to estimate the welfare effects from R&D in a country, such as Germany, whose aquaculture production is small compared to total EU-15 production. We already pointed out that many details of aquaculture R&D and production are not accounted for in our models and scenarios in order to maintain a high transparency of the model and traceability of the scenarios.

For all scenarios the simulation period is 21 years: from 2010 to 2030. Net benefits are discounted to the base year to obtain present values of net benefits. The literature on the choice of discount rates is vast. Following the discussion by ARROW (1995), we settled for a real discount rate of 3 %. As we do not know the costs of R&D responsible for the supply shifts, an internal rate of return cannot be computed.

Based on fish-market characteristics for EU-15-countries described in the previous section, three base scenarios are investigated using IFPRI´s DREAM model. Measures of producer and consumer surplus are computed and compared between the scenarios. In addition, we varied the strength of the spillover effect (θ_{ij}) between 0 (no transmission of R&D from Germany to the rest of EU-15) and 1 (equal supply shifts in Germany and the rest of EU-15). Further, scenarios are computed with adoption lags (λ_A) between 0 and 3 years.

Scenario 1: R&D effects only in Germany

In the first scenario it is assumed that R&D takes place in Germany only. Despite the small size of German aquaculture, some German states, such as Schleswig-Holstein, have initiated sizeable aquaculture R&D-programs with the objective to foster local aquaculture industries, including suppliers of aquaculture technologies. The scenarios assume that R&D leads to a reduction of producer´s cost by 5 %. In the remaining EU-15-countries no R&D-induced supply shifts occur and there are no technology spillovers between Germany and the other regions.

Furthermore it is assumed that it takes three years for the development of a new technology and another two years for its diffusion in the industry. These research and adoption lags may be too short compared to actual lags but data on lags for aquaculture technologies are not available. Pardey and Craig (1989) found strong evidence that the impact of agricultural R&D may take as long as thirty years to be felt. Length of research lags depends on the type of research. Alston et al. (2008) suggests research lag and adoption lag of 5 to 10 years or longer in agricultural R&D. In recent years, improvements in the transmission of information have led to shorter adoption lags (ALSTON et al. 2008).

Scenario 2: R&D in Germany with spillovers to all other EU-15-countries

International spillovers from agricultural R&D play an important role for economic development and agricultural productivity growth (ALSTON 2002). The experience with Norway's salmon R&D has shown that spillovers are also important in aquaculture (TVETERÅS and BJØRNDAL 2001).

The second scenario takes R&D spillovers into account. The new technology is assumed to originate in Germany but can be immediately transferred to and adopted in all other EU-15-countries. The new technology is assumed to be complementary to existing technologies. That means that the spillover coefficient θ is set to 1 for all cases where Germany is the spillout region and the remaining EU-15-countries are the spillin regions. All other spillover coefficients are set to 0.

Scenario 3: R&D in Germany with time-lagged spillovers to all other EU-15-countries

In Scenario 3 the new technology is not immediately available for all EU-15-countries with the exception of Germany. A 3-year lag until adoption is assumed for aquaculture producers outside Germany.

RESULTS

Table 2 presents the computed net present values (NPV) of producers and consumers surplus for each EU-15-country which occur through R&D in aquaculture.

Total NPV benefits are lowest in scenario 1, where the “new technology” is only adopted in Germany. If spillovers are allowed, the transfer and the adoption of the “new technology” in EU-15 aquaculture industry leads to a twelve to fifteen times higher NPV of total benefits. Allocation of total NPV benefits is similarly in all scenarios: producers gain roughly two-third of total benefits and consumers receive round about one-third.

In scenario 1 German aquaculture producers profit through R&D and reach positive benefits, while all aquaculture producers outside Germany receive a negative net benefit. Additionally, German producers benefit outweighs negative benefits of all other producers, so that total NPV benefit of producers is positive. Consumers achieve positive welfare effects through slightly lower prices than it would be the case in the scenario without research. Total benefits are positive for nearly all countries. Only in countries with relative low consumption compared to production, like Denmark and Greece (see table 1), negative total benefits occur.

Spillovers of R&D from Germany to all other EU-15-countries lead to large increases in NPV´s of producers and consumers surplus. Only German aquaculture producers receive a lower surplus than it is the case in scenario 1. The new technology leads to lower production costs and thus to a higher production and lower prices than it would be the case without research. Countries with highest initial production quantity (see table 1) also achieve highest NPV´s of producer benefits.

Compared to scenario 2, in scenario 3 NPV´s of producers and consumers benefits decrease because of the adoption lag in all technology importing countries. Only German producers profit slightly of this time-lag and their NPV of producer surplus increases by nearly 4 %.

Results underline the importance of international R&D projects and the transfer of technologies for total welfare measured by producer and consumer surplus.

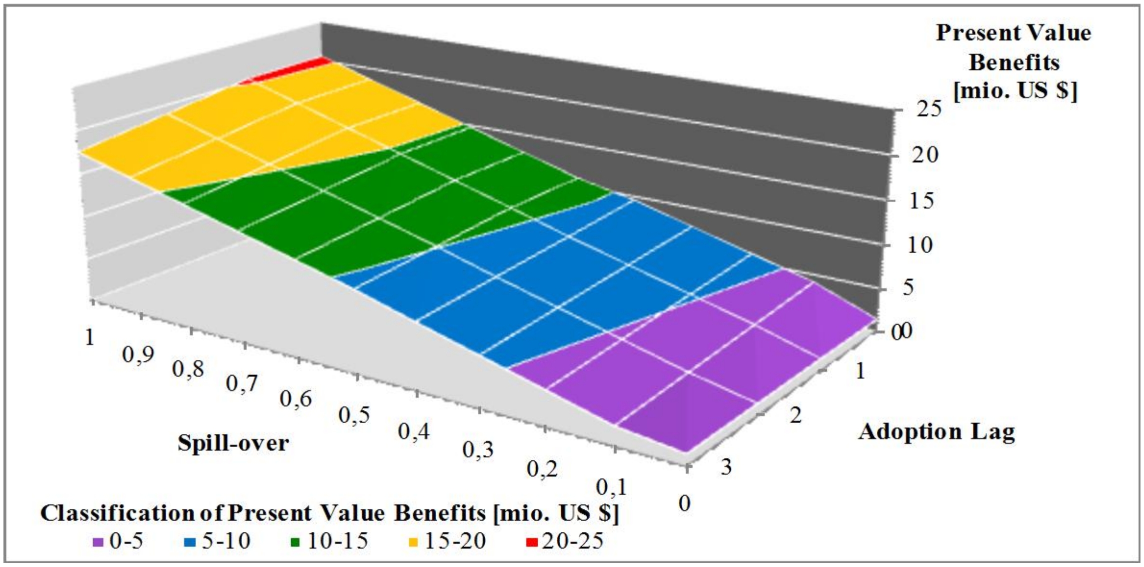
A sensitivity analysis with inelastic demand (-0.8) and elastic demand (-1.5) did not change the qualitative results of this scenario analysis. Additionally it could be stated that the more elastic demand gets, the higher is producer's surplus and the lower is consumer´s surplus.

Table 2: Summary of net present value benefits for producers, consumers and in total of the three scenarios (in 1,000 US $)

Country	Scenario 1			Scenario 2			Scenario 3		
	Producer	Consumer	Total	Producer	Consumer	Total	Producer	Consumer	Total
Austria	-72	616	544	8,245	9,624	17,869	6,570	7,844	14,414
Belgium	-7	1,297	1,291	515	20,268	20,783	411	16,545	16,955
Denmark	-1,052	583	-469	65,098	9,126	74,225	51,954	7,376	59,330
Finland	-395	1,241	847	35,607	19,365	54,972	28,389	15,905	44,294
France	-1,468	9,412	7,944	108,142	147,203	255,345	86,266	119,492	205,759
Germany	98,774	7,122	105,896	83,695	111,450	195,145	86,697	89,881	176,578
Greece	-2,497	1,353	-1,145	268,522	21,073	289,595	213,995	17,415	231,410
Ireland	-383	529	146	42,948	8,235	51,182	34,223	6,855	41,078
Italy	-1,516	5,681	4,165	153,381	88,920	242,301	122,253	71,471	193,724
Netherlands	-284	2,092	1,807	31,738	32,671	64,409	25,291	26,559	51,850
Portugal	-126	3,206	3,080	15,623	50,155	65,778	12,446	40,337	52,783
Spain	-1,734	8,324	6,590	144,325	130,087	274,411	115,092	105,869	220,961
Sweden	-145	1,490	1,346	12,687	23,258	35,945	10,116	19,074	29,190
UK	-4,271	7,160	2,889	414,676	111,695	526,371	330,553	91,632	422,185
Total NPV Benefits	**84,824**	**50,107**	**134,931**	**1,385,200**	**783,131**	**2,168,331**	**1,124,256**	**636,255**	**1,760,511**

Figure 2 shows the present value benefits when spillovers vary between 0 and 1 and when the adoption lag is modeled between 0 and 3 years.

Figure 2: Surface Model of EU-15-wide present value benefits in relation to spillover and adoption lag



The returns of R&D are more sensitive to spillovers than to the adoption lag. Table 3 shows the results of a linear regression on the simulation results.

Table 3: Linear regression on scenario analysis results

Variable	unstandardized coefficients		standardized coefficients	t-statistic	significance
	regression coefficient	standard error	Beta		
Constant	234259.214	22287.828		10.511	.000
Adoption Lag	-67509.526	7428.155	-.135	-9.088	.000
Spillover	1797343.338	27105.353	.988	66.310	.000

CLOSING REMARKS

In this study we focused only on R&D conducted in Germany and its welfare effects on the EU. Scenario 1 showed that aquaculture R&D in Germany leads to positive welfare effects in all EU countries, although producers outside Germany receive negative benefits. Scenarios 2 and 3 indicate that international research spillovers significantly increase the benefits from aquaculture R&D. Hence the main qualitative result is that EU support for aquaculture R&D conducted in Germany benefits all countries of the EU. The variation of spillover and adoption lags showed, that it does not matter much for total EU-15 economic surplus when R&D products are transferred, as long as they are transferred.

In addition to the usual caveats concerning data availability, functional forms, and other technical matters, we are unsatisfied with our model and its results for three reasons. (i) We know next to nothing about the spillovers from R&D on one fish species to the rest; (ii) we know next to nothing about domestic or cross-border adoption lags of aquaculture technologies, and finally (iii) our model treats new knowledge gained in R&D only as an output and the fact that such knowledge also is the crucial input for further R&D activities is not taken into account.

Aquaculture is a relatively young branch of the food producing bioindustries. Like R&D in most young industries, aquaculture R&D has grown rapidly and significant advances can be expected in the near future (STRICKER et al. 2009; FAO 2009a). Continued R&D growth and advances will, however, only be realized if public investment in aquaculture R&D remains at levels commensurate with the benefits that can be had from it.

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APPENDIX

In this appendix the formulae of the model described before are presented.

Equation (1) specifies the supply of fish:

(1) $$Q_{i,t} = \alpha_{it} + \beta_i \, PP_{i,t}.$$

The quantity produced *Q* in country *i* in the year *t* is a function of the producer price *PP*. The slope of the supply curve is determined by β and the axis intercept is given by α.

The quantity consumed in each region is a function of the consumer price in each region $PC_{i,t}$ and the slope of the demand curve is defined by δ, while the intercept of the demand equation is given by γ. Demand for fish *C* in country *i* at time *t* is defined by equation (2):

(2) $$C_{i,t} = \gamma_{it} + \delta_i \, PC_{i,t}.$$

Exogenous growth rates are incorporated to reflect growth in demand and supply that is expected to occur regardless of whether the research program of interest is undertaken.

(3) $$\alpha_{i,t} = \alpha_{i,t-1} + \pi^Q_{i,t} Q_{i,t} \qquad \text{for } t > 0$$

(4) $$\gamma_{i,t} = \gamma_{i,t-1} + \pi^C_{i,t} C_{i,t} \qquad \text{for } t > 0$$

where $\pi^C_{i,t}$ is the exogenous growth rate of demand and $\pi^Q_{i,t}$ is the exogenous growth rate of supply.

The introduction of R&D leads to a downward shift of the supply curve. Let country *i* undertake a program of research with a probability of success p_i, which, if the research is successful and the results are fully adopted, will yield a cost saving per unit of output equal to c_i percent of the initial price, $PP_{i,0}$ in country *i*, while a ceiling adoption rate of A_i^{MAX} percent holds in country *i*. Then it is anticipated that the supply function in region *i* will shift down (in the price direction) by an amount per unit equal to:

(5) $$k_i^{MAX} = p_i \, c_i \, A_i^{MAX} \, PP_{i,0} \geq 0.$$

Our model only considers research lags (λ_R) and adoption lags (years from initial adoption to maximum adoption: λ_A). As disadoption of technologies is not regarded here, the supply shifts (in the price direction) for region *i* in each year *t* can be calculated as follows:

(6) $$\mathrm{k}_{\mathrm{i,t}} = 0 \qquad (\text{for } 0 \leq \mathrm{t} \leq \lambda_{\mathrm{R}})$$

(7) $k_{i,t} = k_i^{MAX}(t - \lambda_R)/\lambda_A$ (for $\lambda_R < t \leq \lambda_R + \lambda_A$)

(8) $k_{i,t} = k_i^{MAX}$ (for $t > \lambda_R + \lambda_A$)

R&D could also lead to supply shifts in other countries, when the new technology is adopted in foreign countries and spillovers occur. These spillover effects of research from one country *i* to another country *j* can be parameterized in relation to the supply shifts in region *i*, whereas θ in equation (9) is the supply shift in *j* due to a supply shift in *i*. This implicitly assumes the same adoption curve in each country.

(9) $k_{j,t} = \theta_{ji}\ k_{i,t} \quad \forall\, i, j$

Research effects are included into the supply curve by adjusting the intercept α. In the "with-research" case, denoted by superscript *R* on the parameters, α is defined by equation (10):

(10) $\alpha_{j,t}^R = \alpha_{j,t} + k_{j,t}\beta_{j,t}$

Supply and demand equations in the "with-research" case are given by equation (11) and (12), respectively. They reflect the local and spillover effects of research.

(11) $Q_{i,t}^R = \alpha_{i,t}^R + \beta_{i,t}PP_{i,t}^R$

(12) $C_{i,t}^R = \gamma_{i,t} + \delta_{i,t}PC_{i,t}^R$

The model is solved by introducing a market-clearing rule by equation (13):

(13) $Q_t = \sum_{i=1}^n Q_{i,t} = \sum_{i=1}^n C_{i,t} = C_t$

Under the assumption of free trade, producer prices *PP* equal consumer prices *PC* in the cases with and without research.

(14) $PP_{i,t}^R = PC_{i,t}^R = PC_{j,t}^R = PP_{j,t}^R = P_t^R$

(15) $PP_{i,t} = PC_{i,t} = PC_{j,t} = PP_{j,t} = P_t$

The market clearing prices under free trade are given by equations (16) and (17)

(16) $P_t = (\gamma_t - \alpha_t)/(\beta - \delta)$

(17) $P_t^R = (\gamma_t - \alpha_t^R)/(\beta - \delta)$

whereas $\gamma_t = \sum_{i=1}^n \gamma_{i,t}$; $\alpha_t = \sum_{i=1}^n \alpha_{i,t}$; $\alpha_t^R = \sum_{i=1}^n \alpha_{i,t}^R$; $\delta_t = \delta = \sum_{i=1}^n \delta_{i0} < 0$; and $\beta_t = \beta = \sum_{i=1}^n \beta_{i0} > 0$. As $\gamma_t > \alpha_t^R > \alpha_t$ it follows that $P_t > P_t^R$.

Regional welfare effects through research can be determined and equations (18) and (19) show the difference in welfare in the case with research and without research.

(18) $\Delta PS_{j,t} = \left(k_{j,t} + PP_{j,t}^R - PP_{j,t}\right)\left[Q_{j,t} + 0{,}5\left(Q_{j,t}^R - Q_{j,t}\right)\right]$

(19) $\Delta CS_{j,t} = \left(PC_{j,t} - PC_{j,t}^R\right)\left[C_{j,t} + 0{,}5\left(C_{j,t}^R - C_{j,t}\right)\right]$

whereas $\Delta PS_{j,t}$ is the R&D-induced change in producer surplus in region *j* in year *t* and $\Delta CS_{j,t}$ is the R&D-induced change in consumer surplus in region *j* in year *t*.

For a planning horizon of *m* years, $\Delta PS_{j,t}$ and $\Delta CS_{j,t}$ can be calculated for each region and each year. After a real discount rate $r_{i,t} = r_{j,t} = r$ is defined, which is the same for each country; it is easy to estimate the present values of benefits (*VPS*, *VCS*) through research:

(20) $VPS_i = \sum_{t=0}^m \Delta PS_{i,t}/(1 + r)^t$

(21) $VCS_i = \sum_{t=0}^m \Delta CS_{i,t}/(1 + r)^t$