Simulating the Spillover Benefits from R&D by a small producer country embedded in a Network: Aquaculture R&D in Germany

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INTRODUCTION

Animal husbandry is undergoing a rapid revolution. To the small number of economically relevant domesticated terrestrial animal species a large number of aquatic species have been added during the past decades and more will follow soon. (DUARTE *et al.* 2007).

The husbandry of aquatic species is not a recent invention. In China, aquaculture has been practiced for economic gain since 475 B.C. (NASH 2011). Aquaculture has, however, not been an important source of food until recently. In 1950, when world population stood at 2.52 billion people, world aquaculture production had reached 1 million tons, equivalent to 0.40 kg of aquaculture product per capita. Until 2008, world population had grown by 260 percent to 6.71 billion people but aquaculture production had grown more than fifty-fold to 52.5 million tons so that per capita availability of aquaculture products had increased to 7.8 kg in 2008 (FAO 2011). According to FAO (2011), no other food industry has been growing as quickly as aquaculture.

Two developments have contributed to the rapidly increasing importance of aquaculture as source of food. One is the growing world demand for fish. Global annual per capita consumption of fish has increased from about 10 kg in the 1960s to about 17 kg in 2008 FAO (2011). The other reason is the dire state of the world's capture-fishery resources which have been depleted because they are owned by nobody in particular. World capture fishery production stagnates at around 90 million tons of fish per year and it is expected to decline (FAO 2011). Aquaculture production, in contrast, has been growing at about 8.3 percent per year and it is expected to provide more than half of global fish consumption by 2012 (FAO 2011).

Several factors contribute to the rapid advance of aquaculture. Whereas our traditional farm animals have been domesticated by illiterate savages, aquaculture species are domesticated by highly trained personnel in sophisticated R&D labs. Moreover, many more aquatic species are suitable for domestication than there were suitable terrestrial species (DUARTE *et al.* 2007). In addition, aquaculture production systems do not evolve by trial and error but are designed using knowledge and insights gained in scientific experiments and computer simulations. Finally, aquaculture R&D is, by and large, an open and global undertaking.

Our paper is motivated by the belief that economics can contribute to the historical advance of aquaculture. We are aware that R&D may generate many economic benefits that escape ready measurement. We nevertheless believe that public support for aquaculture R&D is strengthened if R&D is informed by an *ex ante* analysis of its potential economic benefits. For this purpose we have built a simulation model that we have used to assess the potential welfare effects of aquaculture R&D conducted in Germany. Our model is distinguished by two features: Because aquaculture in Germany is small in comparison to other EU countries, we take R&D-spillover effects to other EU countries into account. Moreover, we correlate the size of R&D-spillovers across EU countries to the strength of fishery and aquaculture research cooperation that we have measured in a bibliometric study (SEIDEL-LASS 2009).

For reasons of data availability, we are only concerned with the EU-15 member countries. This study focuses on the production and consumption of finfish from aquaculture and excludes mollusks, crustaceans and aquatic plants. We do not consider possible effects on markets for substitutes or externalities nor on upstream or downstream markets.

We have organized our paper into four sections. After the introduction we provide some background on aquaculture R&D and on our bibliometric study of international cooperation in fishery research. In section 3 we recapitulate the standard theory of measuring the welfare benefits of R&D and in section 4 we introduce the DREAM-simulation model (ALSTON *et al.* 1995; WOOD *et al.* 2000) together with the data that we used to specify the model. In section 5 we present three model scenarios together with their model results. Section 6 concludes the paper.

AQUACULTURE PRODUCTION AND R&D-NETWORKS IN GERMANY AND IN THE EU

Aquaculture Production in Germany and the EU-15

Aquaculture is a small industry in Germany compared to the industries of the major aquaculture producers in the EU. In 2008 Germany produced some 44,000 tons of aquaculture products or 3.7 percent of EU-15 aquaculture production in that year (Table 1). Germany's contribution to world aquaculture production is insignificant at 0.08 percent of the world total.

Had the EU-15 existed in 1970 it would have contributed more than 16 percent to world aquaculture production which stood at 2.57 million tons in that year. Even though aquaculture production in the EU-15 has nearly trebled to 1.18 million tons in 2008, its share in world aquaculture production has dropped to 2.2 percent because world production has grown more than twentyfold to 52.5 million tons in 2008.

In 2008 the five largest EU-15 producers jointly account for close to 82 percent of total EU-15 production. Germany, which was the (virtual) EU-15 fifth largest aquaculture producer in 1970, has dropped to rank eight even though its aquaculture production has grown by 86 percent in the four decades from 1970 to 2008.

Aquaculture R&D

Expansion of aquaculture has been driven by consumer demand, better policies and governance, and by R&D breakthroughs (FAO 2011). Even though Europe is a small producer by world standards, Europe's R&D achievements in aquaculture are deemed "remarkable" by FAO (2011, p. 155). The prime example is salmon R&D in Norway where production costs fell by nearly 70 percent in the period from 1982 to 1997 (ASCHE et al. 1999; ASCHE 1997). But the EU also has invested heavily in aquaculture R&D. During the 6th Research Framework Programme (2002 2006) aquaculture R&D has 100 mio. and the EU-Commission regards the continued R&D support as essential for the development of aquaculture (EU 2009).

Even though Germany's aquaculture production is currently low, some states in Germany, such as Schleswig-Holstein, a northern seaboard state, 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 immediate economic impact on consumers and producers may not be the most important consideration for their promoters and funding agencies. Although local interests may loom large on the agendas of local funding agencies, R&D research issues of general interest are not suppressed, and local funding agencies make no efforts to prevent R&D to spill over to other aquaculture producing states and countries.

Table 1: Development of aquaculture production(1) in the EU-15 and in the World, 1970-2008.

	2008			1970			
	t	% EU-15	% World	t	% EU-15	% World	(1970-2008)
Spain	249,062	21.2	0.47	156,200	37.4	6.09	59
France	237,833	20.2	0.45	106,444	25.5	4.15	123
Italy	181,469	15.4	0.35	28,632	6.9	1.12	534
United Kingdom	179,187	15.2	0.34	444	0.1	0.02	40,257
Greece	114,888	9.8	0.22	1,040	0.2	0.04	10,947
Ireland	57,210	4.9	0.11	3,701	0.9	0.14	1,446
Netherlands	46,622	4.0	0.09	86,000	20.6	3.35	-46
Germany	43,977	3.7	0.08	23,477	5.6	0.91	87
Denmark	35,337	3.0	0.07	9,272	2.2	0.36	281
Finland	13,439	1.1	0.03	999	0.2	0.04	1,245
Sweden	7,595	0.6	0.01	373	0.1	0.01	1,936
Portugal	6,458	0.5	0.01	47	0.0	0.00	13,640
Austria	2,087	0.2	0.00	870	0.2	0.03	140
Belgium	126	0.0	0.00	0	0.0	0.00	
Luxembourg	-	-		-	-	-	-
EU-15	1,175,290	100.0	2.24	417,499	100.0	16.26	182
World	52,546,205			2,566,882			1,947

(1): Fish, crustaceans, mollusks, etc; not aquatic plants.

Source: FAO (2008), own calculations.

R&D spillovers and networks

Spillovers of useful knowledge from one application domain to another are ubiquitous in agricultural research (Alston 2002) and they are present in aquaculture research. For example, salmon R&D conducted in Norway has spilled over into salmon R&D conducted outside Norway and into R&D on other fish species (TVETERÅS and BJØRNDAL 2001). Mediterranean aquaculture producers, in particular, have appropriated some technologies from Norway to boost their production of sea bream and sea bass.

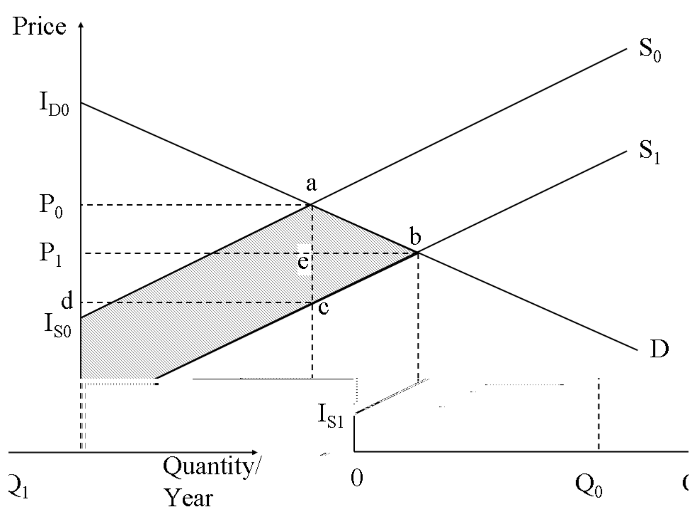
"Spillover" is a metaphor but the term does not specify a mechanism by which useful knowledge actually moves from the "haves" to the "have-nots". Identifying communication channels through which such knowledge may be transferred is one step towards specifying a spillover mechanism. Co-authorships of research papers are such communication channels and are readily measurable with the help of bibliographic databases, such as ISI's Web of Science, and bibliometric methods (GLÄNZEL 2003).

Given the fundamentally unobservable character of knowledge spillovers, directly quantifying their magnitude is a difficult task. To overcome this problem we relate spillover on a network analysis of co-authored publications in aquaculture and fisheries in EU-15-countries. Co-authorships of nearly 13,750 scientific papers published in the aquaculture and fishery research journals that are covered by ISI's Web of Science have been measured and analyzed by SEIDEL-LASS (2009) for the period 1990 to 2005. Based on the publications for 2005 we selected 113 publications for which the author address information indicated residence in an EU-15 member country.

BASIC ECONOMICS OF R&D IMPACT

For the evaluation of R&D benefits, we use a standard commodity market model with linear supply and demand (ALSTON *et al*. 1995). 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.

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



Source: ALSTON *et al.* (1995)

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.

Spillovers occur if R&D results from one country *i* are also adopted in another country *j*. The supply shift in country *i* at time *t*, $k_{i,t}$, is then transferred to country *j* via a spillover coefficient θ_{ji}. The strength of the supply shift $k_{j,t}$ in country *j* is therefore equals ($k_{i,t}\times\theta_{ji}$).

The magnitude of the spillover effect can be of equal or less strength than in the technology originating country, so that the spillover coefficient θ_{ji} is defined between 0 and 1. The number of co-authored papers of each country pair identified by the bibliometric analysis was scaled between 0 and 1 by dividing each number by the maximum of the observed number of collaborations. The spillover coefficients from Germany to the other EU-15 member countries are shown below in Table 3.

DREAM AND DATA FOR ITS SPECIFICATION AND PARAMETERIZATION

DREAM is a software package that implements the model presented above. DREAM has been used in several R&D impact studies (You and Bolwig 2003; Benin and You 2007, Jones *et al.* 2005) including studies of the degree and scope of R&D spillovers (Omamo *et al.* 2006).

DREAM requires that markets always clear. This is ensured by introducing a virtual
, in our case, meets excess demand from the EU-15, which is by far the largest single market for imported fish (FAO 2011).

For each country the market for aquaculture fish has to be specified for the first period $t=0$. The markets are characterized by (i) quantities of supply and demand; (ii) exogenous growth of supply and demand; (iii) elasticities of supply and demand; (iv) initial prices; (v) supply shift parameter $k_{i,t}$, and (vi) technology spillover parameter θ_{ji}.

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. 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) project an annual percentage growth rate (APR) of 2.1 percent for EU-15 aquaculture production between 1998 and 2020. Additionally Failler (2007, 2008) predicts an APR of less than 0.7 percent 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).

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 percent 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 for each EU-15 country.

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. STEEN *et al.* (1993) estimated an intermediate (2 years) supply elasticity of 1 and a long-run (4 years) supply elasticity of 1.54 for Norwegian farmed salmon and this long-run estimation is adopted by KINNUCAN and MYRLAND (2000). BONNIEUX *et al.* (1993) used a short-term supply elasticity of 1.1 and a long-term price elasticity of 2.5 for the modeling of the French trout production sector. 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 percent) 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 that the new technology leads to a per unit cost reduction of 20 percent.

Table 2 summarizes 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.

Table 2: 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

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 percent.

Based on fish-market characteristics for EU-15-countries described previously, three base scenarios are investigated using IFPRI´s DREAM model. Measures of producer and consumer surplus are computed and compared between the scenarios.

<u>Scenario 1: R&D effects only in Germany</u>

In the first scenario we assume that R&D in Germany induces a reduction of production costs by 20 percent. There are no spillovers from Germany to the rest of the EU-15 (θ_{ji}=0). Furthermore, we assume a four year R&D period $_{R}$=4), which is needed to conduct R&D and an adoption lag of four years $_{A}$=4) until the new technology is gradually adopted. 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. ALSTON *et al.* (2008) suggest research and adoption lags of 5 to 10 years or longer in agricultural R&D.

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

The second scenario differs from the first in that we take R&D spillover into account, which are presented in Table 3. Producers in countries like Austria, Belgium; Denmark, Greece, the Netherlands, Portugal and the United Kingdom will benefit from the new technology developed in Germany, while the others will not. For countries where θ_{ji}=0 no co-authored publication could be detected for the year 2005. Subsequent to the research lag of 4 years (= $_{R}$), the new technology can immediately be transferred to and adopted in other spill-in countries. The same adoption curve of the new technology is assumed in each country.

Table 3: Spillover coefficients (θ_{ji}) from Germany to EU-15 member countries

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	UK
Germany	0.125	0.125	0.25	0	0	-	0.25	0	0	0.25	0.125	0	0	0.375

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

In scenario 3 the new technology is not immediately available for all EU-15-countries after the 4 years of technology development (= $_{R}$) with the exception of Germany. A 3-year spillover lag is introduced for aquaculture producers outside Germany, while the adoption lag of German producers is unchanged $_{A}$=4).

Results

Table 4 presents the computed net present values (NPV) of producers and consumers surplus for each EU-15-country which originates from aquaculture R&D.

Table 4: 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	-249	2,133	1,883	2,953	7,720	10,673	2,227	6,474	8,701
Belgium	-22	4,494	4,472	203	16,279	16,482	157	13,665	13,822
Denmark	-3,631	2,005	-1,626	54,826	7,267	62,093	41,716	6,058	47,773
Finland	-1,361	4,318	2,957	-4,905	15,636	10,731	-4,106	13,184	9,078
France	-5,066	32,480	27,414	-18,251	117,663	99,412	-15,289	98,384	83,095
Germany	362,938	24,463	387,402	352,407	88,592	440,999	354,723	73,737	428,460
Greece	-8,608	4,725	-3,882	224,594	17,106	241,700	171,749	14,487	186,237
Ireland	-1,320	1,858	538	-4,761	6,727	1,966	-3,982	5,727	1,745
Italy	-5,225	19,468	14,243	-18,836	70,483	51,647	-15,760	58,526	42,766
Netherlands	-980	7,224	6,244	26,537	26,150	52,687	20,298	21,889	42,186
Portugal	-435	10,990	10,555	5,658	39,777	45,435	4,275	33,044	37,318
Spain	-5,979	28,774	22,795	-21,547	104,213	82,666	-18,041	87,297	69,256
Sweden	-499	5,179	4,680	-1,800	18,755	16,955	-1,507	15,797	14,290
UK	-14,723	24,885	10,161	554,051	90,099	644,150	425,302	75,906	501,207
Total NPV Benefits	**314,837**	**172,998**	**487,835**	**1,151,127**	**626,468**	**1,777,595**	**961,761**	**524,174**	**1,485,935**

-15 aquaculture industry leads to a NPV that is three times larger than in scenario 1. 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 the negative producer benefits, so that total NPV benefit of producers is positive. Consumers receive positive welfare benefits through slightly reduced prices. Total benefits are positive for nearly all countries. Only in countries with relative low consumption compared to production, like Denmark and Greece (see Table 2), negative total benefits occur.

Scenario 2 shows how important the transmission of knowledge or technologies to other countries can be. Spillovers of R&D from Germany lead to large increases in NPV´s of producer surplus in spill-in countries (θ_{ji}>0). Losses of producers surplus in countries to which no spillovers are transmitted (θ_{ji}=0) are higher than in scenario 1. The new technology leads to lower production costs and thus to a higher production and lower prices than would be the case without research.

Compared to scenario 2, NPV benefits of R&D adopting producers decrease in scenario 3 because of the spillover lag. The losses of non technology adopting countries are dampened. Only German producers profit slightly of this time-lag. Consumer surplus decreases slightly because of the delayed technology adoption.

Figure 2: Sensitivity analysis of the scenario results

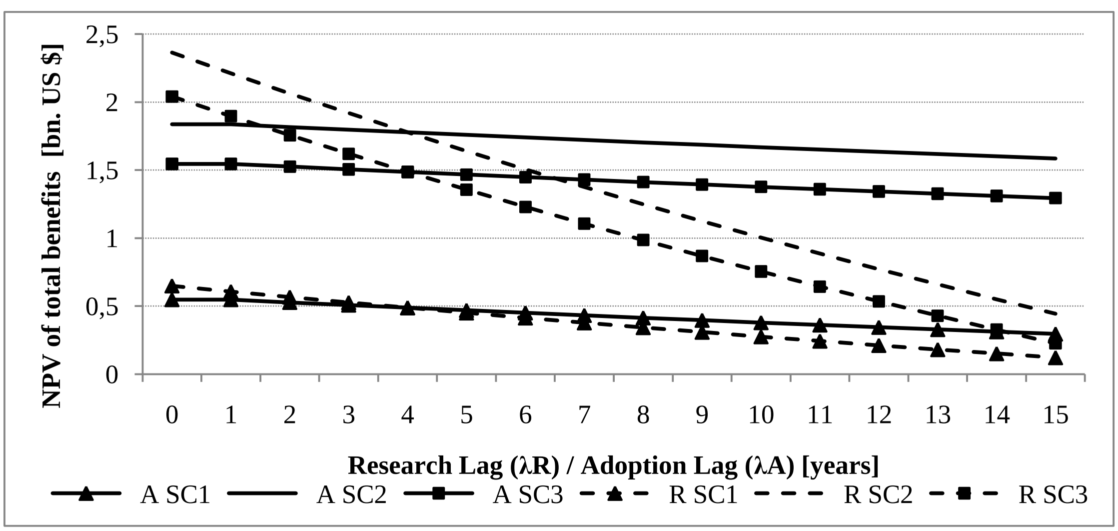


Figure 2 presents a sensitivity analysis of the scenario results according to changes in the research lag and the adoption lag respectively. The total NPV benefits react much more sensitive to changes in the research lag than in the adoption lag.

Results from simulation studies must be interpreted with caution. Our data are mostly estimates and some are guesses. The results of the scenario analysis are therefore at best rough approximation of actual welfare effects. Much more interesting than the quantitative results are the qualitative insights of our scenario analysis. Especially large producer countries benefit from the transfer and adoption of new technologies. Spillovers of knowledge lead to an increase of producers and consumers benefits. The dispersion and diffusion of knowledge and research results is therefore an economic activity which should not be neglected and may warrant continued support.

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 spill-in countries of the EU.

In addition to the usual caveats concerning data availability, functional forms, and other technical matters, we are less than fully satisfied with our model and its results for three reasons: (i) We know very little about the spillovers from R&D on one fish species to the rest or from one production system to another; (ii) our knowledge about domestic or cross-border adoption lags is less than satisfactory, 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. Outputs of R&D tend, however, to encourage the discovery of even more new knowledge and inventions and a path-dependent, recursive invention process may emerge in aquaculture (ARTHUR 2009).

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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