Vaccination of Poultry against *Campylobacter* in the EU – What are the Benefits?

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Abstract.

The European Food Safety Authority (EFSA) and the European Center for Disease Prevention and Control (ECDC) analyses information on the occurrence of zoonosis and food-born outbreaks submitted by the 27 EU member states in its annual report (EFSA, 2012). Among the 13 zoonosis monitored, *Campylobacter* is the most commonly reported gastrointestinal bacterial pathogen in the EU since 2005. Reportedly, 212,064 humans have been confirmed ill in 2010 due to a *Campylobacter* infection in the EU, which is probably only the tip of the iceberg.

The major source of infection, among sporadic human cases is to be found in the food chain, from farm-to-fork, where poultry meat is considered to be one of the major vehicles of *Campylobacter* infections in humans, accounting for 50 to 80 per cent of reported cases.

One way to reduce this socio economic loss to society is perhaps the introduction of a new *Campylobacter* vaccine, which could be administered to day old chicks. This would effectively reduce the outbreak of illness among the general population, enhancing general wellbeing and increase the efficiency of the employed labor force.

In the present paper, we attempt to assess the potential economic benefits of a mandatory vaccination program at the EU27 level. In the study, benefits are mainly assumed to comprise lower risk of illness due to *Campylobacter* infections, and hence increased productivity, as well as some consumer preference for safer chicken meat. In the modeled analysis presented in this paper, the possible price of the vaccine is estimated when it is assumed that: *i)* the number of reported confirmed human *Campylobacteriosis* cases in the EU is reduced by 75 percent, (*ii)* an import ban on non-vaccinated chicken meat into the EU is implemented, (*iii)* an increased preference for EU chicken meat outside the EU increases exports marginally and *(iv)* that the aggregate EU welfare has to remain unchanged as measured by the equivalent variation in income.

Introduction

The European Food Safety Authority (EFSA) and the European Center for Disease Prevention and Control (ECDC) analyse information on the occurrence of zoonoses and food-borne outbreaks submitted by the 27 European Union (EU) member states in its annual report (EFSA, 2012). Among the 13 zoonoses monitored, *Campylobacter* is the most commonly reported gastrointestinal bacterial pathogen in the EU since 2005. The number of reported confirmed human *Campylobacteriosis* cases in the EU has been increasing in the later years, as reflected in the notification rate, which has increased from 45,6 per 100,000 population in 2009 to 48,6 per 100,000 population in 2010. Reportedly, 212,064 humans have been confirmed ill in 2010 due to a *Campylobacter* infection in the EU, and this is probably only the tip of the iceberg, as a considerable share of infections are never reported.

The major source of infection, among sporadic human cases is found in the food chain, from farm-to-fork, where poultry meat is considered to be one of the major vehicles of *Campylobacter* infections in humans, accounting for 50 to 80 per cent of reported cases[1]. The prevalence of *Campylobacter* does not decrease notably from live animals along the food chain to retail when chicken meat is processed[2]. This increases the possibility of cross-contamination (from chicken meat to human) during food preparation in the home and occurrence of human infections (Rosenquist et al., 2003). Hence, the *Campylobacter* bacteria in slaughtered chicken meat represents a health hazard among consumers who risk infection resulting in illness, which in turn would reduce the effective hours of work supplied by the employed labor force and the wellbeing of the general public (Havelaar et al., 2005).

The occurrence of *Campylobacter* in fresh chicken meat samples tested by individual EU member states has remained at a stable high level since 2006, where on average approximately 30 per cent of the samples were reported positive each year. At the retail sampling level, 13 member states have reported the occurrence of *Campylobacter* in fresh chicken meat over the 2008–2010 time period. In four countries (Czech Republic, France, Luxembourg, Slovenia), over 50 per cent of the samples were *Campylobacter* positive while six countries (Austria, Belgium, Hungary, Latvia Netherlands, Italy) had lower than 25 per cent of the samples positive, and with the remaining countries (Denmark, Germany, Spain) having between 25 and 50 per cent positive. However, since the number of samples, testing methods and time of year when samples are taken vary between member states it is difficult to reach general conclusions as to where the highest/lowest probability of getting a *Campylobacter* infection is in the EU from consuming chicken meat.

One potential way to reduce this socio-economic loss to society could be the introduction of a new *Campylobacter* vaccine, which could be administered to day-old chicks (e.g. Zoete et al., 2005). This might effectively reduce the outbreak of illness among the general population,

[1] The EFSA's Panel on Biological hazards estimated in its scientific opinion that 50 to 80 per cent of *Campylobacter* infections can be attributed to the chicken reservoir of *Campylobacter* as a whole.

2 The opposite is true about fresh pig and bovine meat. Sample data collected indicate that the proportion of positive samples is much higher in pig and cattle populations than in samples of fresh pig and bovine meat at processing and retail (EFSA, 2012).

enhancing general wellbeing and increase the efficiency of the employed labor force. But if such a vaccination program should effectively protect the consumers from *Campylobacter* infections from chicken meat, it is also necessary to ban imports of chicken meat from outside the EU.

Recognizing the potential benefits of a *Campylobacter* vaccine, it must also be acknowledged that the cost of developing, manufacturing and applying such a vaccine will increase the rearing cost of a slaughter chicken. Given the expected public health benefits (including derived productivity gains) and the value of consumers' increased confidence in foods, the research questions of the present paper are: how much is society "willing to pay" for a mandatory EU-wide vaccination program? How large are the economic spill-overs from such an EU program on other parts of the world?

In the following we begin by outlining the research methodology for analyzing economic impacts of a *Campylobacter* vaccine in different parts of the world. We then give a short overview of the global production and trade with chicken meat and how large a share of meat supply in the EU is catered for by chicken meat. This is followed by results of the model analysis, which determines the price of a vaccine when it is assumed that: *i)* the number of reported confirmed human *Campylobacteriosis* cases in the EU is reduced by 75 percent, (*ii)* an import ban on non-vaccinated chicken meat into the EU is implemented, (*iii)* an increased preference for EU chicken meat outside the EU increases exports marginally and *(iv)* that the aggregate EU welfare has to remain unchanged as measured by the equivalent variation in income. Finally, implications of the results are discussed and put into perspective.

Methodology and data

It is a complex matter to calculate the socio-economic effects of increased poultry rearing costs, including effects on domestic demand, public health, labor productivity, international trade and national income/welfare among different countries/regions of the world. In this study, we utilize a global general equilibrium (GE) model and its associated database. Equality of demand and supply in all markets is a specific feature of GE models, and we use this setting to calculate the socio-economic effect of introducing a compulsory vaccination program across the European Union. In particular, the modeling framework is used to estimate the economic benefits of a mandatory vaccination program, and hence the maximum costs of the vaccine, if the program should be welfare improving from an economic point of view, when international trade effects are taken into account.

The general equilibrium modeling framework is also used to estimate the consequences of introducing an import ban of non-vaccinated chicken meat into the EU and an increased demand for poultry meat exports from the EU to the rest of the world due to consumers' awareness of the higher standards of EU poultry hygiene levels (reduced prevalence of *Campylobacter* in poultry meat). The advantage of using a general equilibrium model is that it comprises the whole economy of a country, divided into many sectors mutually dependent through purchases of inputs and sales of output traded both domestically, as well as exports to other countries. The model thus enables us to analyse the effect of introducing *Campylobacter* vaccinations at the farm level and how it affects

other sectors of the economy, ultimately manifesting itself in changed trade flows, employment and other macroeconomic indicators found in the model.

More specifically, we use the Global Trade Analysis Projects (GTAP) version 8 database, which represents the global economy in the year 2007 (Narayanan et al., 2012). In the database, the global economy is represented by 127 countries/regions which each produce, consume and trade 57 aggregated commodities among each other. In the present analysis, the GTAP database has been aggregated to 16 countries/regions as shown in Table 1, focusing on the EU countries and the major exporters and importers of chicken meat, while on the commodity side the database has been aggregated to 12 commodities. Due to the aggregated nature of the commodities specified in the GTAP database, additional calibration of the initial database is required.

For the current purpose, the GTAP database has been extended with detailed broiler supply balance data. Hence, the two GTAP commodities "other animal products" and "other meat products" have to be split into four commodities in order to specify primary chick production (live chickens) and secondary processed chicken meat, respectively, in the database. This is necessary because the vaccination against *Campylobacter* takes place in the production of live chickens, before they are sold to the slaughter houses producing the final meat product being consumed and traded around the world.

The calibration of the cost structure in production of live chickens, total product value, consumption and trade with chickens has to be specified for the 17 country/region aggregation of the GTAP version 8 database[3]. In order to do this, values of production and trade were taken from FAOSTAT's agricultural database for the year 2007, and data on initial cost structure of chicken production were taken from the FADN data set for specialized chicken producers in the EU. The production of live chickens was then assumed to be delivered mainly as an input to slaughter houses, however with a share of live chicken being exported as breeding animals or going directly to consumers in other countries. Data on the total value of the production of chicken meat leaving the slaughter house in the EU for the year 2007 were taken from EUROSTAT's Prodcom database, which contains statistics on production of manufactured goods (EUROSTAT 2012). The initial values of global trade with chicken meat were calibrated into the database using 2007 trade data from FAOSTAT.

As is apparent from the short discussion of the recalibration of the GTAP database above, a lot of attention has been given to the calibration of the production cost structure of live chick production as well as the values of chicken meat production in the EU. Some more general assumptions have been used in the remaining countries/regions specified in the database, where the average cost shares of the EU have been used to calibrate other regions (due to lack of available data for these regions). This is not considered to be an important problem, since: *i*) the model scenarios in this paper are focused on changing cost shares in the EU due to the introduction of a compulsory *Campylobacter* vaccination program, and *ii*) the effect of this EU vaccination program

[3] The recalibration of the database was done using the SplitCom program (Horridge 2005) to disaggregate the two GTAP sectors, "other animal products" and "other meat products".

is then transmitted to the rest of the world through the initial trade flows, which have been calibrated using FAOSTAT data, as EU production prices increase. Therefore, the initial calibration of live chicken and chicken meat production in the database is well suited to estimate the effect of introducing *Campylobacter* vaccinations at the farm level in the EU and its effects on other countries around the world through changed trade flows.

As mentioned, we introduce a *Campylobacter* vaccination program in the EU27, together with an import ban on non-vaccinated chicken meat and an increased preference for EU exports in the modeled scenario in this paper. The effect of such a program on global trade is probably minor in the short run, given the present-day trade structure. As can be seen in Table 1, where initial FAOSTA data used to recalibrate the GTAP base is highlighted, the EU27 produces 8.7 million tons of chicken meat, of which 2.0 million tons is exported, and 1.7 million tons is imported. But a large part of this trade is intra EU trade between member states, accounting for 1.6 million tons. [4] The EU27 only imports 0.155 million tons of chicken meat from non-member countries, mainly Brazil, which account for roughly 1.8 per cent of all chicken meat consumed in the EU27. Therefore, imposing an import ban would have a minimal effect on trade flows in the short run. But isolating the EU market from the rest of the world could become costly for EU consumers in the long run, if future low cost non-EU producers are excluded from the EU market.

Notably, there are no imports into the EU27 from the USA. This because the EU imposed an import ban from the USA dating back to 1997 due to the use of certain pathogen reduction treatments (PRT) in the USA to rinse poultry carcasses (meat) for microbes (*Campylobacter* and *Salmonella* among others). Even though the USA has raised this issue in the World Trade Organization (WTO) the EU maintains its import ban stating that the EU generally opposes such chemical interventions and believes that stronger sanitary practices during production and processing are more appropriate for pathogen control than overreliance on PRTs (Johnson 2012). The EU has imposed import bans on chicken meat in the past and could expand this to non-vaccinated chicken meat if this is deemed to be an important part of EU food safety regulations.

EU27 exports to non-member countries are predominately exports from France and to a lesser extent exports from Germany and the United Kingdom. Together, these three countries account for 70 per cent of the EU exports to non-member countries. On the global market, excluding EU intra trade, the main exporting countries are USA and Brazil accounting for 80 per cent of world exports, while the EU is a minor player outside the EU capturing 8 per cent of exports to non-member countries, an export that constitutes about 6 per cent of EU27 production. Given this relative small market share of global exports outside of the EU27, an increased marketing of *Campylobacter* free chicken meat in non-member countries may only have a small impact on EU production, even though demand increases by 10 or 20 per cent.

[4] In table 1 the quantities of production and trade are measured in tonnes, but the GTAP data base is comprised of value flows. Therefore these quantities are indirectly calibrated into the database using the associated values of production and trade found in the FAOSTAT database.

The average meat supply/consumption in the world amounts to roughly 41 kg/capita per year, of which roughly 25 per cent is accounted for by chicken meat (11 kg). There is a large variation in the amount of chicken meat supplied/consumed among the different regions/countries in the world. Taking the USA and the EU27 as examples, the average supply of chicken meat is roughly 47 and 17 kg per capita per year, respectively, accounting for roughly 40 and 20 per cent of total meat supply in these two regions. Among the EU27 countries there is also a large variation in supply of chicken meat per capita per year, with Spain consuming 26 kg per capita compared to Germany's 8 kg, cf. Table 1.

Given this variation in the amounts supplied/consumed, the impact of vaccinating against *Campylobacter* in day-old chicken should vary between countries since the odds of getting ill should be proportionate to the amount of chicken meat eaten, taking into account the level of hygiene in the slaughter house supplying the meat. The worst case scenario is of course low hygiene standards combined with large per capita consumption. In the scenario presented in this paper, the modeled reduction of 75 percent in the number cases reported ill due to *Campylobacter* infections in the EU as a whole, is translated into percentage reductions in the number of ill relative to the amount of chicken meat consumed per capita in each member state.

Table 1. World production, trade and per capita supply of chicken meat, 2007

	Kg/capita /year	Production 1000 ton			Importing countries/regions, 1000 of tonnes														
				*Total export**	Dnk	Ger	Fra	UK	Ita	Nld	Pol	Esp	Rom	Rest of EU27	Total EU27	China	Russia	M East	Rest of world	Total non EU27
Denmark	18	172		97		7	2	11	0	1	1	0	5	48	75	1	2	1	18	22
Germany	8	688		246	6		13	24	2	43	2	12	4	49	156	3	70	2	15	90
France	13	921		302	4	17		33	5	5	2	10	1	38	115	12	31	131	14	188
United Kingdom	23	1270		226	0	11	30		0	59	12	9	3	31	155	4	2	0	64	71
Italy	12	733		41	0	6	2	4		2	0	1	2	19	34	0	0	0	6	6
Netherlands	21	684		567	3	115	48	169	5		11	6	42	127	526	9	8	3	22	41
Poland	21	896		116	0	19	10	24	1	6		0	4	35	100	7	0	0	9	16
Spain	26	1131		31	0	1	8	2	2	1	0		1	13	28	0	1	0	1	3
Romania	19	312		1	0	0	0	0	0	0	0	0		0	1	0	0	0	0	0
Rest of EU27	19	1916		430	9	45	95	52	4	74	5	5	19	68	377	1	19	1	31	52
Total EU27	17	8724		2055	24	220	208	318	19	191	33	44	81	428	1567	36	132	138	182	489
USA	47	16628		2410	0	0	0	0	0	0	0	0	0	0	0	556	878	23	953	2410
Brazil	35	8988		2394	0	16	5	10	3	39	0	34	19	5	130	484	184	708	887	2263
Rest of world**	7	40803		728	0	6	0	11	0	3	0	1	0	3	24	245	9	45	404	703
Total non EU27	11	66419		5531	0	21	5	21	3	41	0	35	19	7	155	1285	1071	776	2244	5376
Total world	11	75143	*Total import*	7586	24	242	213	339	22	232	33	80	100	435	1721	1321	1204	914	2426	5865

Source: FAOSTAT statistics and own calculations.

Note: * The trade data presented in this table is taken from the FAOSTAT web site using the quantity of imports reported by countries.

**The composition of the aggregate region “Rest of World” includes China, Russia, Meddle East and rest of the world in third bottom row of table 1, while in the second last column the “Rest of World” includes USA Brazil and rest of the world. This distinction/aggregation has been made because the USA and Brazil are major exporters while China, Russia and the Middle East are major importers.

Results

The modeled scenario is the introduction of a *Campylobacter* vaccine administered to day-old chicks in the entire EU27. It is assumed that the vaccine price in absolute terms will be the same in all EU27 member countries. Looking at the European Commission's market price statistics for chicken, it can be seen that prices vary for a whole class A chicken, presentation 65% between the individual member countries (e.g. between 219 €/ton slaughter weight in Germany to 134 €/ton in Poland), which means that when the absolute vaccine cost is uniform across all member countries, then the percentage increase in production cost will vary between countries relative to the attained market price for a sold chicken. This is also reflected in the model results shown in Table 2 below.

Table 2 shows the effects of the vaccination program on production, per capita supply and trade in different regions. It can be seen from the table that the increased production price of chicken meat, due to the vaccination program, has reduced the per capita supply in the EU by 0.2% on average. But the production of chicken meat has actually increased by 2.6% in the EU, due to the import ban on non-EU chicken meat originating mainly from Brazil and increased marketing of EU chicken meat to third countries. This exclusion from the intra market bolsters intra-EU trade by 7.9 percent, which is enough to raise EU production, even though domestic supply declines. Notably, the production of chicken meat within the EU increases in Germany by 6.7% while at the other end Poland's production declines by 0.4%, which is not surprising, given the assumed relative cost of implementing the vaccine program in these countries. The Netherlands' production of chicken meat also increases notably by 7.3% spurred on by its initial large share of intra-EU exports and the exclusion of Brazil and other non-member countries from the EU market.

Looking at the EU as a whole, the results show that if the vaccination program is implemented without restricting imports from third countries, and if there is no extra-EU willingness to pay a price premium for EU-produced meat from vaccinated chicken, then production within the European Union would decline by 0.4%. The introduction of the import ban increases EU production by 2.4%, as there is then no alternative supply of chicken meat in the intra EU market. Finally, the modeled willingness to pay for *Campylobacter* free chicken meat outside of the EU boosts EU aggregate production by 0.6%.

Table 2. Percentage changes in the quantity of world production, traded and per capita supply of chicken meat.

	Capita /year	Production		*Total export*	Importing countries/regions: Dnk	Ger	Fra	UK	Ita	Nld	Pol	Esp	Rom	Rest of EU27	Total EU27	China	Russia	M East	Rest of world	Total non EU27
Denmark	-0.1	3.7		4.7		8.2	1.6	3.7	13.6	32.9	2.1	46.7	14.3	1.5	3.2	14.5	15.0	15.0	14.8	14.8
Germany	-0.1	6.7		17.8	4.2		5.1	7.2	17.4	37.4	5.6	51.6	18.2	4.9	17.6	18.2	18.8	18.7	18.6	18.7
France	-0.1	3.3		13.1	3.1	10.8		6.1	16.3	36.1	4.5	50.1	17.0	3.9	10.6	17.1	17.8	17.6	17.1	17.5
United Kingdom	-0.2	1.5		12.6	2.2	9.8	3.0		15.2	34.8	3.5	48.7	15.9	2.9	12.0	16.0	16.9	16.5	16.4	16.4
Italy	-0.3	0.3		4.2	-1.1	6.3	-0.3	1.7		30.5	0.1	43.8	12.3	-0.4	3.7	-10.3	0.4	0.3	12.6	12.3
Netherland	-0.4	7.3		6.9	2.5	10.1	3.3	5.5	15.6		3.9	49.1	16.3	3.2	6.6	16.4	17.0	17.2	16.8	16.8
Poland	-0.3	-0.4		-0.6	-5.8	1.2	-5.1	-3.2	6.2	24.3		37.0	7.2	-5.0	-1.1	7.1	0.4	7.0	7.4	7.4
Spain	-0.3	1.5		2.1	-1.2	6.3	-0.3	1.6	11.5	30.6	0.2		12.4	-0.4	1.7	12.3	12.9	12.6	12.7	12.7
Romania	-0.5	1.4		8.6	10.2	6.3	11.2	13.4	24.3	30.6	11.7	60.4		-0.6	8.4	0.0	0.4	0.3	11.8	11.8
Rest of EU27	-0.3	1.7		7.5	-1.2	6.1	-0.4	1.6	11.4	30.3	0.1	43.7	12.2	-0.4	7.2	12.1	12.8	12.3	12.6	12.6
Total EU27	-0.2	2.6		11.5	2.1	8.2	1.1	4.4	14.2	33.2	3.2	49.6	14.8	1.9	7.9	15.1	17.6	17.5	15.1	16.4
USA	0.0	-0.1		-1.7											-100	-0.6	-2.4	-3.6	-1.9	-1.7
Brazil	-0.1	-2.8		-10.8	No imports into the EU from other countries. Reduced to zero tons (-100%)										-100	0.1	-1.7	-2.9	-1.2	-1.6
Rest of world	0.0	-0.1		-9.7											-100	-0.7	0.4	-3.2	-1.5	-1.3
Total non EU27	0.0	-0.5		-7.5	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-0.4	-2.2	-2.9	-1.4	-1.6
Total world*	-0.1	0.1	Total import	-0.7	0.1	-3.1	-1.5	-1.2	-3.5	-1.4	3.1	-11.9	-1.5	0.4	-1.5	0.0	-0.1	0.0	-0.3	-0.2

Note * The total percentage change in world supply and production should of course be the same, which they are not in the results shown in this table. World supply declines by 0.1% while production increase slightly by 0.1%. This discrepancy occurs because the GTAP database consists of values flows which are used to aggregate percentage changes in quantities at country level to regional and world level results.

If we assume that 75 per cent of the *Campylobacter* cases in EU27 can be avoided as a result of a mandatory vaccination program, this corresponds to a reduction in illness cases of about 159,000 per year (table 3).

Table 3. Reduction in number of people ill from *Campylobacter* infections

	2007 General Employment level	Increased Labour Productivity (%)	Increased work force	Reduction in number of ill people *
Denmark	2,852,800	0.0019	55	2,194
Germany	38,541,500	0.0009	340	13,582
France	25,885,100	0.0014	359	14,371
United Kingdom	29,363,900	0.0024	705	28,213
Italy	23,404,700	0.0013	298	11,936
Netherland	8,592,700	0.0023	194	7,768
Poland	15,799,800	0.0023	357	14,296
Spain	20,257,600	0.0028	564	22,567
Romania	9,369,100	0.0020	190	7,585
Rest of EU27	47,236,900	0.0020	927	37,090
Total EU27	221,304,100	0.0018	3,990	159,603

Source. Eurostat and own calculations.

Note * At the EU level the increased labor productivity of 0.0018% translates into increasing the work force by 3,976 fulltime employees. If these employees work each 200 days a year and a Campylobacter infection takes averagely 5 days to recover from, the vaccination program is required to reduce the number of ill people by roughly 159,000.

The GTAP database/model estimates that labor productivity would increase on average by 0.0018% in the EU due to reduced sick leave, assuming that the vaccination program does not affect the unemployment rate in the EU. When the amount of hours worked increases, this would in the first instance put a pressure on the economy to reduce employment, since the same amount of output can be produced with a reduced labor force. This would reduce the cost of producing outputs (commodities), increasing the EU's relative competiveness on the global market, which would on the other hand increase demand for EU produced goods. This second round effects of increased demand for EU produced commodities would then again increase employment in the EU.

As can be seen from Table 3 the calculated labor productivity gains vary between member states. This is because the labor productivity gain at the EU level is weighed relative to the amount of chicken meat supplied per capita in each member state. In Table 1, it can be seen that Germany has the lowest consumption of chicken meat per capita in the EU and is hence assumed to have a lower occurrence of *Campylobacter* infections among the population compared to other countries with a higher consumption of chicken meat. In Table 3 labor productivity is estimated to increase by 0.0009% in Germany compared to Spain's 0.0027%, which has the highest per capita consumption of chicken meat.

Looking at the implications of the vaccination program for the European Union's economy, table 4 shows the change in economic welfare expressed as the equivalent variation in income (EV).

Table 4. Equivalent variation in income, million €

		Of which contributions from			
	Change in Income	Preference EU	Import Ban	Vaccination Cost	Labour Productivity
Denmark	2	1	0	-2	4
Germany	13	3	-8	-1	19
France	19	7	0	-11	23
United Kingdom	6	2	-16	-20	41
Italy	-4	0	-8	-13	16
Netherland	-2	2	-14	-0	10
Poland	-10	0	2	-17	5
Spain	-17	0	-22	-19	24
Romania	-10	0	-4	-7	2
Rest of EU27	3	0	-1	-29	33
Total EU27	0	16	-71	-120	176
USA	-18	-11	-10	4	-1
Brazil	-95	-19	-80	4	0
Rest of world	-45	9	-60	0	6
Total non EU27	-158	-22	-149	7	5
Total world	-158	-6	-221	-113	182

The potential productivity gain in EU27 represents an annual value of 176 mill. €. The exclusion of non-EU chicken meat from the intra-EU market also pushes up chicken meat prices in the EU, reducing real income by 71 million €. The modeled willingness to pay extra for *Campylobacter* free EU chicken meat outside of the EU generates an increased demand for EU chicken meat increasing real income by 16 million €. The net effect of these three policies (productivity gain, import ban and increased willingness to pay) is an increase in real income of 120 million € in the EU.

If the vaccination program should be cost neutral at the EU27 level, the EU27 cost of the vaccination program should not exceed 120 mill. €. With an annual EU27 production in the magnitude of 8 billion (Eurostat), this corresponds to 1.65 eurocents per dose of vaccine. It is interesting to notice the differences in the distribution of costs and gains between EU member states, with France, Germany, UK and Denmark obtaining a net gain, while Spain, Poland and Romania will face a net loss, if the vaccine costs 1.65 eurocents per dose. These small loses and gains are explained by the relative differences between member states in, i) the amounts of chicken

meat consumed per capita, ii) the obtained farm gate market price of chickens, iii) the cost share of chickens in processing industries and iv) the initial trade structure.

The model results presented in this article represent a long run closure of the model where these first and second round effects have run their course over time. The GTAP model calculates the maximum vaccine cost to maintain the aggregate EU real income (EV) and adjust labor wages so that employment remains unchanged in each member state, given the above scenario assumptions.

Discussion and conclusion

Campylobacter infections are one of the most widespread zoonoses in European food production. Among a range of intervention types (including e.g. fly screens, changed feeding, rodent control, post-and slaughter decontamination), vaccination of chicken is considered as a strategy to combat human *Campylobacter* infections, and research efforts are devoted to develop and test such vaccines. In the present paper, we attempt to assess the potential economic benefits of a mandatory vaccination program at the EU27 level, assuming that a highly effective vaccine against *Campylobacter* exists. In the study, benefits are mainly assumed to comprise lower risk of illness due to *Campylobacter* infections, and hence increased productivity, as well as some consumer preference for safer chicken meat in extra-EU markets.

The values of these gains were estimated to correspond to about 1.65 eurocent per dose of *Campylobacter* vaccine. A few other studies have attempted to estimate the benefits of reduced *Campylobacter* risk based on a Cost-of-Illness (COI) approach. Mangen et al. (2005a) estimated a total COI of about 21 million € per year in the Netherlands, corresponding to about 255€ per incident (which again corresponds to about 15-20 eurocents per kg broiler meat consumed), where more than two thirds stem from productivity losses, and the rest is related to costs of medical care. Buzby et al. (1996) estimated a value of 468-550 US$ per incident (in 1993 price-level) in the United States, which also included both productivity losses and medical care, although the specific distribution of productivity and health care effects are somewhat difficult to disentangle from this study. Taking potential health care savings into account in our assessment would increase the estimated gains beyond the 1.65 eurocents per broiler.

It should also be noted that further benefits could be imagined. Increased trust in chicken meat among EU consumers might represent an economic value, and might be reflected in a price premium that EU consumers would be willing to pay. Because the scenario of this paper considers a full-scale reduction in *Campylobacter* prevalence in chicken, existing willingness-to-pay studies related to *Campylobacter* risk are not adequate for estimation of this willingness to pay, because they are based on more partial perspectives, where consumers have the choice between e.g. *Campylobacter*-labelled vs. non-labelled chicken meat (Mørkbak et al., 2009). But if a ban on broiler meat imports is assumed to reflect the preferences of the European consumers, the price increase implied from such a ban might be interpreted to represent a lower-end estimate of their additional willingness to pay for the lower *Campylobacter* risk level in EU-produced broiler meat after implementation of the vaccination program.

The benefit estimates in the present study may be considered as comparable with costs of alternative preventive measures. For example, Mangen et al. (2005b) found that the total cost for provision of extra hygiene measures, phage therapy and PCR-tests would cost Dutch broiler farms € 0.05 per bird, however with considerable variation across farms. Jensen et al. (2013) also investigated the costs of *Campylobacter* Risk reduction in a Danish setting, finding similar costs per broiler for ambitious reduction goals, whereas the costs per broiler may be lower for substantially lower risk reduction goals.

It should however be noted, that such an effective vaccine does not exist on the market at the moment, although there are attempts going on to develop such a vaccine. There are no published studies of the costs of developing, manufacturing and delivering *Campylobacter* vaccine to chicken. A number of other (live) vaccines for poultry are available on the market in a price range about 1-2 eurocents per dose. Both whether this will also be possible regarding *Campylobacter* vaccines remains still uncertain.

The unit cost of 1.65 eurocent per dose reflects a scenario, where all chicks all over EU27 should be vaccinated, irrespective of e.g. climatic conditions (which are known to influence *Campylobacter* prevalence in chicken flocks). Average vaccination costs might be reduced by some targeting of the program, e.g. according to climate zone or season, or whether the chickens are destined for chilled or frozen distribution.

We should also be aware that published figures on human *Campylobacter* infections represent a lower-end estimate of the actual number of infected people, due to under-registration. At the EU level the increased labor productivity of 0.0018% translates into increasing the work force by 3,976 fulltime employees. If these employees work each 200 days a year and a *Campylobacter* infection takes averagely 5 days to recover from, the vaccination program is required to reduce the number of ill people by roughly 159,000 if the average real income in the EU is not to decline when the vaccine costs 1.65 eurocent per doses. But perhaps even more importantly the general wellbeing of the European Union's population has increased and lives may have been saved.

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