A PARTIAL EQUILIBRIUM MODEL OF THE LINKAGES BETWEEN ANIMAL WELFARE, TRADE AND THE ENVIRONMENT IN SCOTLAND

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Abstract

This research analyses the impacts of a scientific advance that improves animal welfare, upon the environment and trade in Scotland using partial equilibrium (PE) modelling. The science improves pig neonatal survival through improved (high fibre) sow diets used before mating. Our model simulates the effects of animal welfare changes on the pig production systems (pig meat) and further on trade flows (trade in pig meat) and environment (water and air pollution). We consider two animal welfare simulation scenarios, namely the status quo – no animal welfare change as regards pig neonatal mortality (baseline scenario) and the case of improving pig neonatal survival (alternative scenario) and compare the impacts on trade and environment between the two scenarios during the simulation horizon 2008-2015. The results show that the increase in animal welfare has a lower impact on the environment in the alternative scenario compared to the baseline scenario (by about 6% at the end of the simulation horizon) and a positive impact on net trade in the alternative scenario compared to the baseline scenario (by about 13% at the end of the simulation horizon).

Introduction

The CAP reform has consistently strengthened the role of environment and animal welfare issues in the European Union, however there are still concerns about their impact on trade under the WTO rules. Any approach to assess animal welfare and the creation of strategies, policies and standards must involve a multidisciplinary approach dealing with aspects of production, livestock sciences, legislation, trade and environment. While there has been work done on modelling linkages between animal welfare and trade or between animal welfare and the environment, there has been nothing done yet to simultaneously model all three despite the increasing need to harmonise environmental and animal welfare standards for imports with those faced by domestic producers in ways compatible with WTO rules. Simulations using trade models would make it possible to assess the impact of both environmental and animal welfare regulations on trade and international competitiveness. They would also offer a means to address the externalities of animal welfare, that is, its impacts beyond the farm gate on trade and the environment.

An extensive literature exists on the use of simulation models to estimate the effects of trade on the environment and several authors (Ervin, 1999; Van Beers and van den Bergh, 1996) analyse the different methodologies used to estimate the environmental effects of agricultural trade liberalisation. The most commonly used methods are the partial and general equilibrium models. Partial equilibrium (PE) models are designed to analyse the impacts of the changes in a single sector of the economy, and have been used, for example, to study the effects of environmental policy on specific commodities in the agricultural sector, assuming no changes in the remaining sectors of the economy (see Meilke et al., 1996 and Jayadevappa and Chhatre, 2000 for reviews on the use of PE models for analysing trade and environment linkages). General equilibrium models examine the economy as a whole, taking into account the interlinkages between different sectors and the distributive impacts of agricultural and environmental policy changes (see Bandara and Coxhead, 1999; Lopez, 2000).

Simulations using trade models make it possible to assess the impact of a given regulation that hinders the competitiveness of the particular country that implements it (Beghin and Bureau, 2001). This approach has been used to assess the effects of sanitary and phytosanitary related standards, but it could also assess more recent technical standards related to animal welfare and environmental management emerging in the European Union, the United States, Australia, and elsewhere (Beghin and Metcalfe 2000; Mitchell 2001). Beghin and Bureau (2001) note that an interesting case study would be the combination of animal welfare and environmental constraints in a sector such as pig meat. Several EU members and the United States compete for pig meat export markets, for example, in Asia. The accumulation of new standards or, as is the case of our paper, reduction in production costs may affect their competitiveness in these markets by raising or decreasing their cost of production. Sectoral trade models (e.g. applied PE models) are useful instruments for

estimating the effects of new animal welfare regulations or animal welfare related changes in the production process.

This research analyses the impacts of a scientific advance that improves animal welfare, upon the environment and trade in Scotland using partial equilibrium (PE) modelling. The science improves pig neonatal survival through improved (high fibre) sow diets used before mating. The PE approach models a baseline scenario (equilibrium between demand and supply for pig meat), adds shocks (the change in animal welfare) and sees how the system responds (shifts in prices, quantities, trade and environment). PE models are useful for understanding a particular response to changing policy scenarios and can capture the impacts of small changes that do not (seriously) affect sectors other than agriculture. The paper is organised as following: section 2 presents the theoretical model, section 3 briefly describes the animal welfare scientific experiment and lists the sources for the economic and environmental data; section 4 illustrates the simulation scenarios; section 5 discusses the results and section 6 presents some conclusions.

Theoretical model

Our model simulates the effects of animal welfare changes on the pig production systems (pig meat) and further on trade flows (trade in pig meat) and environment (water and air pollution). The model has three modules, 'production and trade', 'environment' and 'animal welfare'. As regards the 'production and trade' part of the model, we employ a similar approach to other commodity trade partial equilibrium models used for policy evaluation and adapted for the specific case of a pig farm (FAPRI PE model, see Barrett and Fabiosa, 1998; for a comprehensive review of this type of models see McCalla and Revoredo, 2001). As regards the environmental module of the model, we associate the pollution to the use of production inputs, namely link the use of nitrogen inputs (e.g., nitrogenous fertilisers, manure) to nitrogen loss through leaching/runoff into groundwater (nitrates) and greenhouse gases (emissions of nitrous oxide and methane) (Toma, 2006; OECD, 2003). We measure the impact of animal welfare changes on trade and environment indirectly through production. A schematic representation of the model is presented in Figure 1.

Figure 1. Animal welfare, trade and environment PE model
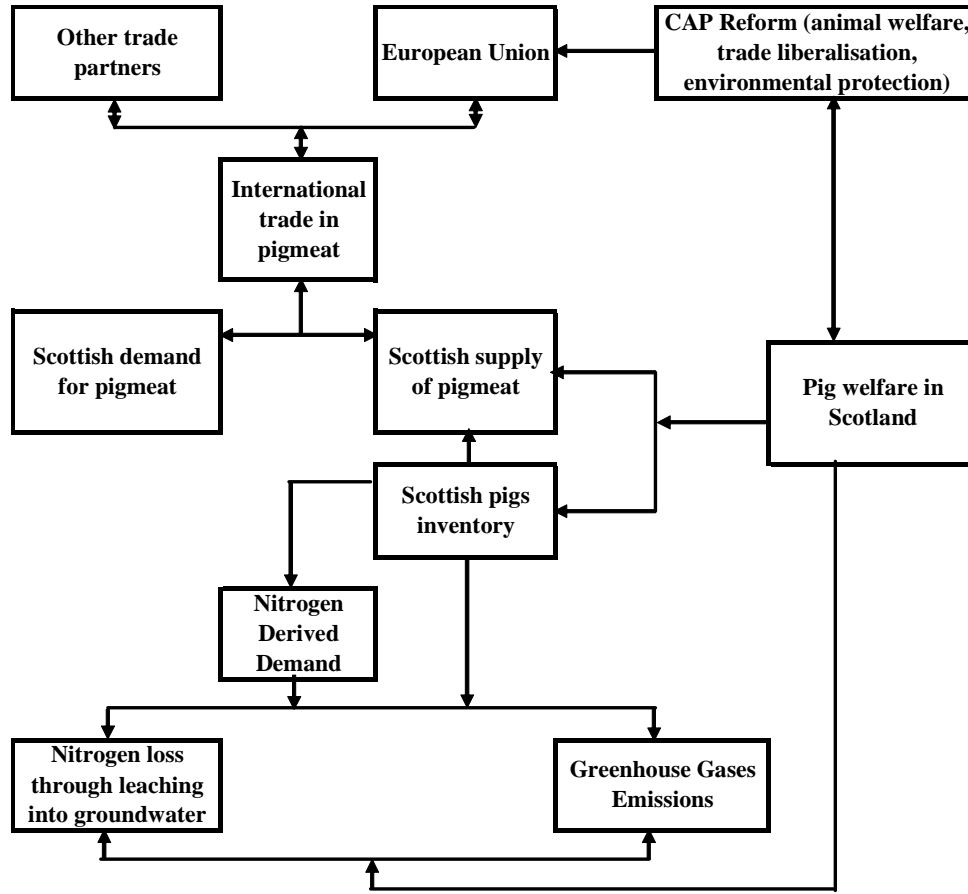
Schematic representation of the PE model, showing the main components and linkages required for the case study

Production and trade part of the model

In terms of notation in the demand, supply and trade equations, the α_s are functions' parameters and the D_i represent dichotomous variables (introduced for the cases of atypical values of the variables in some years) that take value one in the year "i" and zero otherwise.

Demand

The per-capita consumption of pig meat, C_t/Pop_t (where C_t is the total consumption of pig meat at period t and Pop_t is the mid-year Scottish population) is presented in equation (1):

$$\frac{C_t}{Pop_t} = \alpha_0 + \alpha_1 P_t^B + \alpha_2 P_t^C + \alpha_3 P_t^P + \alpha_4 {P_t^B}^2 + \alpha_5 {P_t^C}^2 + \alpha_6 {P_t^P}^2 + \cdot \alpha_7 \left(\frac{I_t}{Pop_t}\right) \tag{1}$$

The per-capita consumption of pig meat depends on the real price of pig meat P_t^P, and the real prices of beef P_t^B and poultry meat P_t^C as substitutes. In addition, equation (1) includes the effect of changes in the per-capita real income I_t.

Supply

The crop of piglets Y_t (i.e., pig production) presented in equation (2) is defined by multiplying the inventories of sows from the previous period, $S_{(t-1)}^S$ by the piglet crop rate[1] r_t^Y (assumed to be a function of its previous period value, a trend variable t and dummy variables, $D_{year\,i}$).

$$Y_t = \left(S_{(t-1)}^s\right) * \left(\alpha_0 + \alpha_1 r_{(t-1)}^Y + \alpha_2 t + \alpha_3 D_{year'i}\right) \qquad (2)$$

Equation (3) presents the number of slaughtered sows H_t^S in the current period, which is equal to the product between the sow inventory from the previous period and the rate of sow slaughter[2] $r_t^{H^S}$ (which is a function of its value from the previous period, the log of real prices for pig meat P_t^P, a trend variable t and dummy variables, $D_{year\,i}$).

$$H_t^s = \left(S_{(t-1)}^s\right) * \left(\alpha_0 + \alpha_1 \log\left(P_t^P\right) + \alpha_3 r_{(t-1)}^{H^B} + \alpha_4 t + \alpha_5 D_{year'i}\right) \qquad (3)$$

The number of slaughtered piglets H_t^{pg} presented in equation (4) is equal to the current piglet crop multiplied by the rate of piglet slaughter[3] $r_t^{H^{pg}}$. This rate is a function of its value from the previous period, the log of real price of pig meat P_t^P, a trend variable t and dummy variables, $D_{year\,i}$.

$$H_t^{pg} = Y_t * \left(\alpha_0 + \alpha_1 \log\left(P_t^{pg}\right) + \alpha_2 r_{(t-1)}^{H^{pg}} + \alpha_3 t + \alpha_{4D_{year'i}}\right) \qquad (4)$$

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[1] The piglet crop rate was defined as the ratio between the number of new piglets and the stock of sows from the previous period.
[2] The rate of sow slaughter was defined as the ratio between the number of slaughtered sows and the inventory of sows in the previous period.
[3] The rate of piglet slaughter was defined as the ratio between the slaughtered piglets and the piglet crop in the current year.

The number of other slaughtered pigs H_t^O presented in equation (5) is equal to the inventory of other pigs from the previous period $S_{(t-1)}^O$ multiplied by the rate of other pigs slaughter[4] $r_t^{H^O}$. This rate is a function of its value from the previous period, the log of real price of pig meat P_t^P, a trend variable t and dummy variables, $D_{\text{year i}}$.

$$H_t^O = S_{(t-1)}^O * \left(\alpha_0 + \alpha_1 \log\left(P_t^p\right) + \alpha_2 \, r_{(t-1)}^{H^O} + \alpha_3 t + \alpha_4 D_{year'i} \right) \qquad (5)$$

The inventory of sows at the end of the current period, S_t^S, presented in equation (6) is a function of its value from the previous period, the log of real price of pig meat P_t^P, a trend variable t and dummy variables, $D_{\text{year i}}$.

$$S_t^s = \alpha_0 + \alpha_1 \log\left(P_t^p\right) + \alpha_2 S_{(t-1)}^s + \alpha_3 t + \alpha_4 D_{year'i} \qquad (6)$$

The number of pig losses through death during the current period, D_t (equation 7) is estimated as the product between the total pig inventory from the previous period (i.e., sows and other pigs) and the pig death rate, r_t^D, which was approximated by an autoregressive function which includes dummy variables, $D_{\text{year i}}$.

$$D_t = \left(S_{(t-1)}^s + S_{(t-1)}^O \right) * \left(\alpha_0 + \alpha_1 \, r_{(t-1)}^D + \alpha_2 D_{year'i} \right) \qquad (7)$$

The estimation of the average carcass weight[5] W_t is done by equation (8). This is an autoregressive equation that also includes the rate of piglet slaughter, a trend variable t and dummy variables $D_{\text{year i}}$

$$W_t = \alpha_0 + \alpha_1 W_{t-1} + \alpha_2 \, r_t^{H^{pg}} + \alpha_3 t + \alpha_4 D_{year'i} \qquad (8)$$

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[4] The rate of other pigs slaughter was defined as the ratio between other slaughtered pigs and the inventory of other pigs from the previous year.
[5] The variable 'average carcass weight' was constructed by dividing the production of pig meat and piglet meat by the total number of slaughtered pigs.

Trade

Equation (9) for imports of live pigs (sows and other pigs), $M_t^{(S+O)}$ is estimated based on the log of the ratio between the domestic price of pig meat and piglet meat and the world price of pig meat and piglet meat. The equation includes dummy variables, $D_{year\ i}$.

$$M_t^{(s+o)} = \alpha_0 + \alpha_1 \log\left(\frac{P_t^p}{P_t^W}\right) + \alpha_2 D_{year'i} \tag{9}$$

Equation (10) for exports of live pigs, $X_t^{(S+O)}$, depends on the log of the ratio between domestic price of pig meat and piglet meat and the world price of pig meat and piglet meat, an autoregressive component, a trend variable t and dummy variables, $D_{year\ i}$.

$$X_t^{(s+o)} = \alpha_0 + \alpha_1 \log\left(\frac{P_t^p}{P_t^W}\right) + \alpha_2 X_{t-1}^{(s+o)} + \alpha_3 t + \alpha_4 D_{year'i} \tag{10}$$

Equation (11) for imports of pig meat and piglet meat M_t^P depends on the log of the ratio between domestic and world prices of pig meat and piglet meat, an autoregressive component and dummy variables, $D_{year\ i}$.

$$M_t^p = \alpha_0 + \alpha_1 \log\left(\frac{P_t^p}{P_t^W}\right) + \alpha_2 M_{t-1}^p + \alpha_3 D_{year'i} \tag{11}$$

Equation (12) for the exports of pig meat and piglet meat, X_t^P, depends on the log of the ratio between the domestic and world prices of pig meat and piglet meat, an autoregressive component and dummy variables, $D_{year\ i}$.

$$X_t^p = \alpha_0 + \alpha_1 \log\left(\frac{P_t^p}{P_t^W}\right) + \alpha_2 X_{t-1}^p + \alpha_3 D_{year'i} \tag{12}$$

Equilibrium

The closure equation (13) for the analysis of the pigs market presents the balance in the inventory of other pigs, S_t^O. This depends on the inventory of other pigs from the previous period $S_{(t-1)}^O$, the changes in the sows' inventory, slaughtered pigs, imports of live pigs, exports of live pigs and number of pigs losses through death during the current period.

$$S_t^O = S_{(t-1)}^O - \left(S_t^p - S_{t-1}^p\right) + \left(Y_t - H_t^s - H_t^o\right) + \left(M_t^{(p+o)} - X_t^{(p+o)}\right) - D_t \qquad (13)$$

Equation (14) presents the balance in the pig meat and piglet meat market S_t^P, which depends on the stock of pig meat and piglet meat from the previous period $S_{(t-1)}^P$, the total production of pig meat and piglet meat (equal to the product between the total number of slaughtered pigs and the average carcass weight), imports of pig meat and piglet meat, domestic consumption of pig meat and piglet meat and exports of pig meat and piglet meat.

$$S_t^p = S_{(t-1)}^p + \left(H_t^s + H_t^O\right)W_t + M_t^p - C_t - X_t^p \qquad (14)$$

The model closes assuming that changes in inventories are adjusted to the current disequilibrium (i.e., excess of supply or demand). However, it is possible to set a value for the change in pig meat and piglet meat inventory and find the domestic price of pig meat and piglet meat that clears the market. The model is recursive dynamic and estimated by ordinary least squares.

Environmental module of the model

In order to simulate the impact in the changing market conditions on production and thus on the environment, the factors affecting nitrogen use and concentrate use are modelled separately. The environmental component of the model consists of an equation estimating the nitrogen loss to leaching (based on nitrogen balance) and an equation estimating the greenhouse gas emissions (specifying GHG as a function of applied nitrogen, number of pigs and related emissions of methane and nitrous oxide converted to carbon equivalents).

Nitrogen loss through leaching/runoff into groundwater

The use of nitrogen per hectare is modelled in several steps. First, we model the conditional demand for each one of the crops included in the feed ration. We assume that the production of pig feed follows a Leontief production function (i.e., fixed proportions technology), where the α_s are the technical coefficients associated to each input and indicate the amount of each input (i.e., component) required for the production of a unit of feed (equation 15).

$$F_t = \min\left\{\frac{F_t^B}{\alpha_B}, \frac{F_t^W}{\alpha_W}, \frac{F_t^{SB}}{\alpha_{SB}}, \frac{F_t^{USBP}}{\alpha_{USBP}}, \frac{F_t^{SO}}{\alpha_{SO}}\right\} \qquad (15)$$

In equation (15) F_t is the production of the feed ration per pig head that depends on barley (F_t^B), wheat (F_t^W), soybeans (F_t^{SB}), unmolassed sugar beet pulp (F_t^{USBP}), salt and others (F_t^{SO}). The conditional demand for grains in the feed ration is given by equation (16):

$$F_t^j = \alpha_j \cdot F_t \cdot \left(S_t^S + S_t^O \right)$$

(16)

To obtain the requirement of nitrogen used as fertiliser per hectare, we transform the total demand for each crop (equation 16) into the number of hectares required for the crop (using the national average yields for the crop, i.e., y_t^j) and then the amount of nitrogen used by means of an input-output coefficient (μ_j). Thus, the use of nitrogen for the crop "j" in the production of feed (N_t^j) is given by equation (17):

$$N_t^j = \mu_j \cdot \left(\frac{F_t^j}{y_t^j} \right)$$

(17)

The total amount of nitrogen loss through leaching/runoff is influenced by the balance between the nitrogen inputs (fertiliser application, mineralisation of organic sources - manure, seeds and planting materials, crop residues, biological fixation - and atmospheric deposition) and outputs (plant uptake, ammonia volatilisation and denitrification).

We compute the nitrogen loss through leaching/runoff into groundwater (GW_t) based on the OECD soil surface nitrogen balance at UK level (Toma, 2006; OECD, 2008) (equation (18)):

$$GW_t = I_t^1 + I_t^2 + I_t^3 + I_t^4 + I_t^5 + I_t^6 - \frac{O_t^1}{d_t}$$

(18)

Where I_t^i $i = 1,..,6$ denotes the nitrogen inputs, namely the nitrogen content of fertilisers (I_t^1), nitrogen content of pig manure production (I_t^2), atmospheric deposition of nitrogen (I_t^3), nitrogen input from biological nitrogen fixation (I_t^4), nitrogen content of seeds and planting materials (I_t^5), and nitrogen content of crop residues (I_t^6). The nitrogen outputs consist of nitrogen uptake by harvested crops and forage for pigs feeding (O_t^1) divided by

annual average drainage measured in mm/year (d_t) and the nitrogen loss through leaching/runoff into groundwater (GW_t).

The nitrogen content of fertilisers (I_t^1) is defined as in equation (19):

$$I_t^1 = \lambda_{Nit} \cdot \left(\sum_{j=H}^{OF} N_t^j \right)$$

(19)

Where $\left(\sum_{j=H}^{OF} N_t^j \right)$ is the total amount of fertilisers used for vegetal crops for feeding pigs measured in MT and (λ_{Nit}) is the fertiliser nutrient conversion coefficient measured in kg / MT.

The nitrogen content of pig manure production (I_t^2) is defined as in equation (20):

$$I_t^2 = \lambda_P \cdot S_t^S + \lambda_O \cdot S_t^O - \lambda_E \left(\lambda_P \cdot S_t^S + \lambda_O \cdot S_t^O \right)$$

(20)

Where λ_M is the coefficient to convert sow numbers into manure nutrient quantity and composition (measured in kg/head/year), λ_O is the coefficient to convert other pigs numbers into manure nutrient quantity and composition (in kg/head/year) and λ_E is the coefficient for the destruction and evaporation of manure.

The atmospheric deposition of nitrogen on agricultural land (I_t^3) is defined as in equation (21):

$$I_t^3 = \lambda_B \cdot \left(\frac{F_t^B}{y_t^B} \right) + \lambda_W \cdot \left(\frac{F_t^W}{y_t^W} \right) + \lambda_{SB} \cdot \left(\frac{F_t^{SB}}{y_t^{SB}} \right) + \lambda_{USBP} \cdot \left(\frac{F_t^{USBP}}{y_t^{USBP}} \right)$$

(21)

Where $\lambda_W, \lambda_{SB}, \lambda_B, \lambda_{USBP}$ are the coefficients to calculate atmospheric deposition of nutrient quantity and composition on areas planted with wheat and, respectively, soybeans, barley and sugarbeet used for feeding pigs (kg/hectare).

The nitrogen input from biological nitrogen fixation (I_t^4) is defined as in equation (22):

$$I_t^4 = \lambda_{BB} \cdot \left(\frac{F_t^B}{y_t^B} \right) + \lambda_{BW} \cdot \left(\frac{F_t^W}{y_t^W} \right) + \lambda_{BSB} \cdot \left(\frac{F_t^{SB}}{y_t^{SB}} \right) + \lambda_{BUSBP} \cdot \left(\frac{F_t^{USBP}}{y_t^{USBP}} \right)$$

(22)

Where $\lambda_{BB}, \lambda_{BW}, \lambda_{BSB}, \lambda_{USBP}$ are the coefficients to calculate biological nitrogen fixation from the areas of barley and, respectively, wheat, soybeans and sugarbeet used for feeding pigs (kg/hectare).

The nitrogen content of seeds and planting materials (I_t^5) is defined as in equation (23):

$$I_t^5 = \lambda_{SB} \cdot SPM_t^B + \lambda_{SW} \cdot SPM_t^W + \lambda_{SSB} \cdot SPM_t^{SB} + \lambda_{SUSBP} \cdot SPM_t^{USBP}$$

(23)

Where λ_{SB}, $\lambda_{SW}, \lambda_{SSB}$, λ_{SUSBP} are the coefficients to convert barley seeds and planting materials and, respectively, wheat, soybeans, sugarbeet seeds and planting materials into nutrient uptake and composition (kg/MT); $SPM_t^B, SPM_t^W, SPM_t^{SB}, SPM_t^{USBP}$ are barley seeds and planting materials and, respectively, wheat, soybeans, sugarbeet seeds and planting materials (1000 MT).

The nitrogen content of crop residues (I_t^6) is defined as in equation (24):

$$I_t^6 = \lambda_R \cdot R_t$$

(24)

Where R are the crop residues (straws) (1000 MT) and λ_R is the coefficient to convert crop residues into nutrient uptake and composition (kg /MT) (straws removed from the field are returned as farmyard manure).

On the output side, the nitrogen uptake by harvested crops and forage for pigs feeding is defined as in equation (25):

$$O_t^1 = \lambda_{HB} \cdot F_t^B + \lambda_{HW} \cdot F_t^W + \lambda_{HSB} \cdot F_t^{SB} + \lambda_{HUSBP} \cdot F_t^{USBP}$$

(25)

Where $\lambda_{HB}, \lambda_{HW}, \lambda_{HSB}, \lambda_{HUSBP}$ are the coefficients to convert the respective crops (barley, wheat, soybeans, sugarbeet) into nutrient uptake and composition (kg/MT).

Greenhouse gases emissions

Greenhouse gases emissions (GHG_t) are incorporated in the model (such as in Toma, 2006; OECD, 2003) as a function of applied nitrogen ($N_t = \sum\limits_{j=1}^{m} N_t^j$) and the number of pigs (equation (26):

$$GH_t = \left(\omega_N \cdot \Omega_0^S + \omega_M \cdot \Omega_{11}^S + \omega_M \cdot \Omega_{12}^S \right) \cdot S_t^S + \left(\omega_N \cdot \Omega_0^O + \omega_M \cdot \Omega_{11}^O + \omega_M \cdot \Omega_{12}^O \right) \cdot S_t^O + \omega_N \cdot \Omega_2 \cdot N_t$$

(26)

Where: Ω_0^S, Ω_0^O are coefficients to convert manure from sows and other pigs into nitrous oxide (N_2O) emissions from manure management (kg N_2O / pig head / year); Ω_{11}^S, Ω_{11}^O are coefficients to convert manure from different categories of pigs into methane (CH_4) emissions from enteric fermentation (kg N_2O / pig head / year); Ω_{12}^S, Ω_{12}^O are coefficients to convert manure from different categories of pigs into methane (CH_4) emissions from manure management (kg N_2O / pig head / year); Ω_2 is a coefficient to convert fertiliser into nitrous oxide (N_2O) emissions (kg N_2O / kg of N).

Methane and N_2O emissions from these sources are converted into their carbon equivalent. The CO_2 equivalent of a non-CO_2 gas is calculated by multiplying the mass of the emissions of the non-CO_2 gas by its relative global warming potential (GWP). Considering the time horizon of 100 years, methane and nitrous oxide are multiplied by their respective GWPs (ω_M and ω_N) to obtain their CO_2 equivalents.

Animal welfare component of the model

The animal welfare component of the model is based on the results of a commercial sow feeding trial described by Ferguson et al. (2004). The experiment analysed the effect of feeding increased dietary fibre from mid lactation until mating on the number of piglets born alive. The fibre source used was unmolassed sugar beet pulp[6] which replaced cereals (mainly wheat) in the diet. Unmolassed sugar beet formed 20% of the lactation diet and 40% of the diet fed between weaning and oestrus.

As regards the link to the 'production and trade' module, the impact of animal welfare issues (i.e., increased piglet survival due to changes in sow's diet) is estimated through the equations in the 'production and trade' module (e.g., 'number of pigs losses through death', 'crop of piglets', 'number of slaughtered sows'). As regards the link to the environmental module, the animal welfare element may affect the environment indirectly through production

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[6] Sugar beet pulp is a by-product of sugar beet. 1000 kg of sugar beet, without the foliage, yield 140 kg of sugar, 58 kg of dried pulp, 40 kg of molasses, 15 kg of beet residue, 60 kg of Betacal and 687 kg of water. Amongst the by-products, the dried pulp and molasses are suitable for feed (Elferink et al., 2008).

or directly through changes in manure composition due to changes in sow's diet. There is no exact data on the change in the sow's manure composition due to the specific modification in diet and the related environmental effects. On the one hand, the addition of dietary fibre (e.g., sugar beet pulp) causes a nitrogen excretion shift from urea in urine to bacterial protein in faeces which might reduce the environmental impact (Nahm, 2003; Aarnink et al., 2007; Hansen et al., 2007). On the other hand, there might be an increase in the methane emissions from manure fermentation, higher for sows than, for instance, growing pigs (Jørgensen, 2007). As we do not have the exact information about how much these contradictory effects counteract each other, and, based on literature we expect the net effect to be negligible, our model assumes no direct environmental effects due to changes in manure composition. Therefore we measure only the indirect environmental effects through production.

Data

Data from the scientific experiment on pig neonatal survival through improved (high fibre) sow diets used before mating – Prof. Cheryl Ashworth, University of Edinburgh; Ferguson et al. (2004). Pig meat and piglet meat balance and livestock balances – Meat and Livestock Commission (MLC) 2008 Yearbook; SAC Farm Management Book 2008/2009. Data on pig meat, beef and poultry – MLC 2008 yearbook; FAOSTAT Database; EUROSTAT database. Price forecasts for all the meat types – estimates based on EU Agricultural Outlook 2008-2017; OECD -FAO Agricultural Outlook 2008-2017. Own-price and cross-price elasticities for beef and the meat substitutes (DEFRA; Scottish Executive Statistics Department). Meat consumption and consumer price indices - MLC yearbook; FAOSTAT Database; EUROSTAT database. Exchange rates information - EUROSTAT. Parameters in the equations of nitrogen loss to leaching/runoff – OECD. Global warming potential coefficients for methane and nitrous oxide – IPCC. Coefficients for methane and nitrous oxide emissions from livestock systems - UNFCCC Greenhouse Gas inventory.

Simulations

We consider two animal welfare simulation scenarios, namely the status quo – no animal welfare change as regards pig neonatal mortality (baseline scenario) and the case of improving pig neonatal survival (alternative scenario) and compare the impacts on trade and environment between the two scenarios during the simulation horizon 2008-2015.

Assumptions of the Baseline scenario:

‒ Traditional diet for sows and implicitly no change in piglet neonatal survival (assume 22 piglets per sow per year);

- We assume the pig and pig meat consumption, production and trade will generally follow the trends forecasted in the EU pig meat market outlook (EC, 2008, EU Agricultural Outlook 2008-2017);

- Per capita consumption of pig meat increases towards the end of the simulation horizon;

- Pig meat production increases slowly during the simulation horizon (at the beginning slowed down by the increase in cereal feed prices, then less so due the stabilisation of prices);

- Pig meat imports from the EU and the rest of UK remain at 2007 levels at the beginning of the horizon and then slow down following the stabilisation of cereal feed prices);

- Pig meat exports to the EU and the rest of UK remain at 2007 levels at the beginning of the simulation horizon and increase slowly afterwards, however the pig meat net trade remains negative during the simulation horizon;

- The total pig stock increases at a slow rate;

- Pig meat prices are predicted to increase steadily by the end of the simulation horizon;

- Wheat prices are expected to fall from the recent peaks, however they will increase by 50% by the end of the simulation horizon compared to the past decade;

- As regards sugarbeet, projections for sugar prices are 30% higher than the last decade, (much lower increase than the increase forecasted for wheat prices). We assume the prices of sugar beet pulp follow a similar trend. Scotland does not produce sugar beet, but imports it from the rest of UK[7] and EU.

Assumptions of the Alternative scenario:

- Alternative diet for sows (wheat partially replaced by unmolassed sugar beet pulp) and implicit improvement in piglet neonatal survival (23 piglets per sow per year).

- We assume no changes in consumption due to changes in consumers' perception about pig welfare.

- We assume the pig and pigmeat consumption, production and trade will generally follow the trends forecasted in the EU pigmeat market outlook (EC, 2008, EU Agricultural Outlook 2008-2017), as presented above under the baseline scenario.

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[7] UK sugar beet production is limited to some 7,000 quota holders, effectively all in England only. Around 9 million tonnes of the UK sugar beet is grown on 150,000 hectares of land. The beet produces about 1.5 million tonnes of white sugar and the residues give 750,000 tonnes of animal feed.

Results and discussion

Impact on trade

The increase in animal welfare has a positive impact on net trade in the alternative scenario (improved sow diet) compared to baseline scenario (traditional sow diet) (by about 13% at the end of the simulation horizon, namely by 14.83% for net trade in live pigs and by 12.40% in pig meat net trade) (Figure 2).

**Figure 2. Trade impact of pig welfare change**
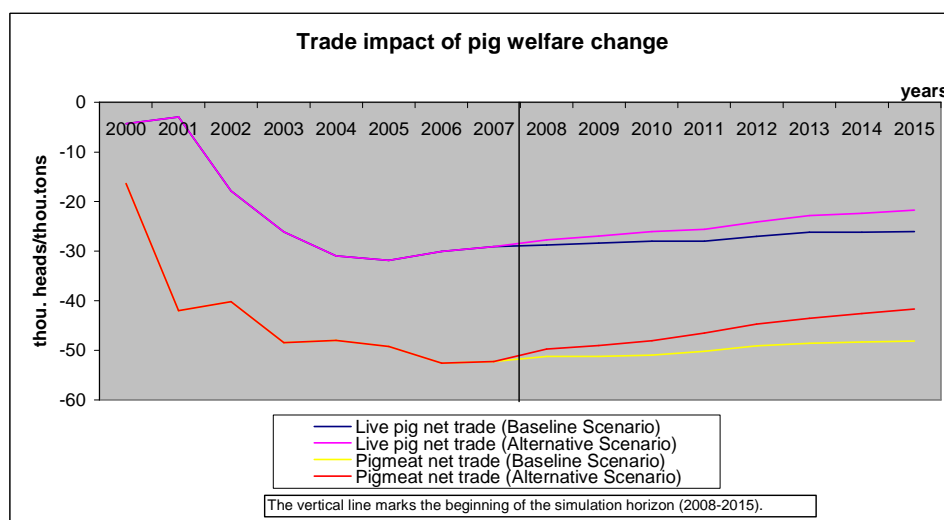
The beneficial effects on trade are due to the increased piglet crop and mainly due to the reduction in production costs due to partially replacing wheat with unmolassed sugar beet pulp. The change in sow diet, if applied at pig industry level would benefit Scottish farmers and improve the current pessimistic forecasts. The current situation of the Scottish pig industry is mainly due to the steep increase in feed prices during the past couple of years, however it has been deteriorating for a longer period. Our model assumes that the change in diet from more expensive to lower cost feed happens only in the Scottish industry, while its trading partners continue to use more expensive feeds. This is realistic during the simulation horizon, however situation might be different in the longer term when not only Scotland, but also its trading partners would have lower feed costs due to the technological change.

Impact on environment

The increase in animal welfare has a lower impact on environment in the alternative scenario (improved sow diet) compared to baseline scenario (traditional sow diet) (by about 6% at the end of the simulation horizon, namely by 6.34% for greenhouse gases - methane and nitrous oxide in carbon equivalent- and by 6.23% for nitrogen loss through leaching/runoff into groundwater) (Figure 3).

Figure 3. Environmental impact of pig welfare change
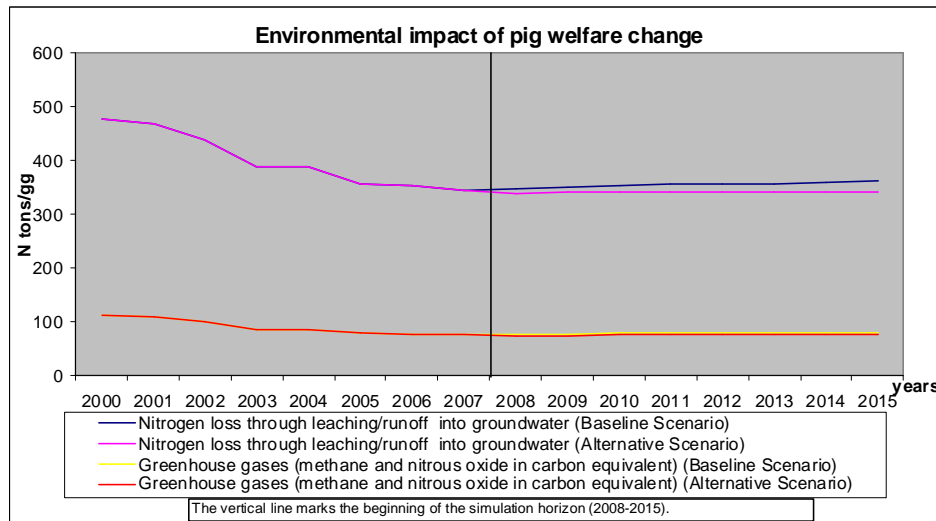
This is due to a combination of factors. First, the production of sugar beet and implicitly its by-products, e.g., sugar beet pulp does not impact the environment in Scotland as Scotland imports sugar beet; therefore the model measures a lower use of nitrogenous fertilisers for the domestic crops included in the modified diet of the sow and, for the same reason, it does not consider the lower nitrogen uptake by sugar beet crop compared with the nitrogen uptake by grain crops (e.g., wheat and barley), which has in itself a negative impact on environment. Second, the change in sows' diet leads to decreased piglet mortality and therefore lower replacement rate for sows and, implicitly, reduced emissions from manure due to reduction in quantities.

As already mentioned, the model measures only the indirect environmental effects through production (i.e., nitrogenous fertilisers use for crops and nitrogen content of sows' manure) and assumes no direct environmental effects due to changes in manure composition. There are diverse and contradictory opinions on the latter issue. Robert et al (1997) stated that, in the case of feeding high fibre diets to sows (offered as a way of partially satiating limit-fed sows), adding fibre to the feed may add to the environmental burden of the farm as non-ruminants do not utilise fibre very well. On the other hand, Fernandez et al. (1999) studied the role of complex dietary carbohydrates (sugar beet pellets) as inhibitors of ammonia emissions from growing pigs in an experiment in which sugar beet pellets replaced 15% of the test feed cereal content. The results showed that the ammonia emission was reduced by about 13% as a consequence of replacing 15% of the diet cereals with sugar beet pellets. Similarly, Canh et al. (1997) also found decreasing pH and ammonia emissions from the slurry when the inclusion of pressed sugar beet pulp silage (SBPS) in the diet of growing pigs was increased. The lower pH of faeces and manure of pigs fed diets with high fermentable dietary fibre content is an efficient means for reducing ammonia emission (Aarnink et al., 2007). Hansen et al. (2007) stated that the addition of dietary fibre into diets

may be a practical method to alter the chemical composition of faeces and slurry. The nitrogen excretion shift from urea in urine to bacterial protein in faeces is a potential means for reducing the environmental load of pig facilities (Nahm, 2003). This is because, while the breakdown of protein in manure is a slow process taking weeks and even months depending on the temperature, the degradation of urea to ammonia and CO_2 covers only several hours (Aarnink et al., 2007). Bindelle et al. (2008) in their review on the nutritional and environmental consequences of dietary fibre in pig nutrition mention several other studies with similar results (e.g., Sutton et al., 1999; Kreuzer et al., 1998).

As Hansen et al. (2007) state, there is still a lot of work to be undertaken on standardisation of dietary composition and on measuring techniques as, under current experimental settings, the effects on the ammonia, methane and nitrous oxide emissions can not be clearly shown. This is also the case of our analysis, where there is no exact data on the change in the sow's manure composition due to the specific modification in diet and the related environmental effects. On the one hand, the nitrogen excretion shift from urea in urine to bacterial protein in faeces might reduce the environmental impact. On the other hand, there might be an increase in the methane emissions from manure fermentation, higher for sows than, for instance, growing pigs (Jørgensen, 2007). As we do not have the exact information and how much these contradictory effects counteract each other, our model assumes no direct environmental effects due to changes in manure composition.

We have also measured the environmental impacts for the hypothetical case that Scotland were a producer of sugar beet and the related environmental effects were not 'exported' to the sugar beet producers from where Scotland imports sugar beet ('Rest of UK' and 'Rest of EU'). The increase in animal welfare has a slightly lower impact on environment in the alternative scenario (improved sow diet) compared to baseline scenario (traditional sow diet) (by about 4% at the end of the simulation horizon). This shows that the use of sugar beet pulp in sow's diet would have a slight positive effect on environment even if sugar beet were produced domestically. Moreover, as sugar beet pulp is a by-product of sugar beet, the change in sow's diet would not have an 'independent' environmental effect as sugar beet is cultivated chiefly for human consumption (sugar production). Only if the demand for sugar beet pulp due to the change in sow's diet at pig industry level exceeds the demand for sugar beet for the production of sugar, would the related environmental effects be directly and solely caused by the pig industry.

Our model only measures the environmental impacts on water and air. There are other aspects not covered here, such as land use and energy use. Elferink et al. (2008) analyse some of the environmental impacts of feed crops for the production of pig meat and compare the land and energy use for grain crops and food residues (here he includes sugar beet pulp and potato peels). One of the conclusions of their study is that the environmental impact (e.g., land use, energy use) of food residue-based feed (e.g., sugar beet pulp) is significantly lower than that of grain-based feed (wheat).

Conclusions

The results show that the increase in animal welfare has a lower impact on the environment in the alternative scenario compared to the baseline scenario (by about 6% at the end of the simulation horizon). As regards the impact on trade, the increase in animal welfare has a positive impact on net trade in the alternative scenario compared to the baseline scenario (by about 13% at the end of the simulation horizon). This is one case when animal welfare improvements have beneficial trade and environmental effects. The model provides policy relevant information and an improved understanding of the interactions between economic and environmental values and animal welfare in the context of CAP reform.

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