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HOW IMPORTANT ARE AGRICULTURAL EXTERNALITIES? A FRAMEWORK FOR ANALYSIS AND APPLICATION TO DUTCH AGRICULTURE

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Abstract

In this paper, we develop a theoretical model for identifying the appropriate welfare measures associated with the positive and negative externalities of agricultural production. Implications of methodological assumptions are discussed, and the model is then used to estimate the costs and benefits associated with the negative and positive externalities of the Dutch agricultural sector. Efforts are made to cross-validate cost estimates empirically, and we also estimate the value of the non-commodity outputs that Dutch farmers provide. The non-market costs and benefits attributable to farming are then set against the value-added of the agricultural sector as a whole. Total value-added benefits are estimated to be €10,604 million a year. The external annual costs are calculated to be €1,868 million, significantly greater than estimated external gross benefits of €263 million, but much less than value added. Using all available information, total average annual net benefits from agriculture in the Netherlands are estimated to be €8,736 million per year for the period 2005 to 2012. Nonetheless, net external costs are equivalent to €849 per ha of arable, horticultural and pasture land, and are high relative to estimates found for other countries.

Keywords: environmental spillovers; applied welfare measurement; agricultural externalities; agricultural value added; non-agricultural commodities

JEL categories: D61, Q15, Q18, Q51, Q57, R11

1. Introduction

The Netherlands is famous for its windmills and unique rural landscape that together led to its inclusion on the UNESCO world cultural heritage list. But the Netherlands is also known for its agriculture. In 2014, the country was the world's second largest exporter of agricultural products after the United States, although it has only 1.89 million hectares of agricultural land or 0.46% of the U.S.'s area. The Netherlands imports livestock feed that facilitates efficient production of meat and dairy products, a large part of which is subsequently exported mostly to the other EU countries. This reflects a competitive, innovative and creative agriculture and agribusiness, but it also portends an intensive agriculture that may easily lead to significant adverse environmental impacts. The Dutch are consequently concerned about the sustainability of this intensive agricultural and food system, and the intended and unintended externality effects it might impose on human health and the environment. In this paper, we provide estimates of the agricultural spillover effects for the Netherlands, measured in economic terms and related to the value added generated by the sector.

The Dutch agricultural sector has experienced many developments since the 1950s, including declining real prices for agricultural products, a reduction in the numbers of farms and agricultural workers, economies of scale realized by surviving farms, substantial growth in labour and land productivity, and a shift towards a more land-intensive form of production (Bruchem et al., 2008). Nonetheless, as a result of high rates of growth in the remainder of the economy, agriculture's share of national income has fallen while industrial agriculture is increasingly viewed as having negative direct and indirect consequences on human health, rural communities and the environment (Pretty et al., 2001; Tegtmeier and Duffy, 2004). Besides its negative impacts, however, agriculture provides beneficial amenities. For example, the farm sector has preserved biodiversity and desirable landscapes (see FAO, 2010).

Agricultural externalities can be positive or negative, but (1) the costs of externalities are often ignored in the evaluation of the sector's contribution to society. Further, (2) externalities generally occur with a time lag, which complicates their measurement; (3) they often damage groups whose interests are not well represented; (4) the origin of an externality is not always known (viz., non-point source pollution); and (5) externalities result in sub-optimal economic and policy outcomes (Pretty et al., 2000). In addition to examining methodological issues in this study, we analyse the costs and benefits associated with externalities in Dutch agriculture. These are important for determining the overall contribution of the sector to society's welfare, along with the sector's measurable direct costs and benefits as reflected by value added. Insight into the external costs and benefits of the farm sector is important because it provides a more integrated picture of the net contribution of agriculture to the Dutch economy, thereby complementing work on green GDP measurement (Boyd and Banzhaf, 2007). Further, it provides insights into the relative impact of different externalities, which can be useful when considering trade-offs between market and non-market goods and services. It may also provide a basis for allocating R&D expenditures and guiding agro-environmental policies that address negative externalities and increase agriculture's value added (Bateman et al., 2013). Finally, the current research might encourage researchers, consumers and agricultural producers to take a closer look at the impacts of industrial agriculture (Tegtmeier and Duffy, 2004), induce them to reflect on changing agricultural and consumer practices that contribute to making agriculture more sustainable (Pretty et al., 2005; Porter et al., 2009), and cause them to rethink multifunctional agriculture.

Several researchers have evaluated the costs and benefits of the externalities associated with agricultural activities. For the UK, Pretty et al. (2000, 2001) estimated that the total external costs of agriculture were substantial, constituting some £233m or 89% of 1996 average net farm income. They recommended that policy should aim to internalise the external costs by redirecting public support from polluting activities to sustainable practices, using subsidies to encourage 'positive' farm activities that are under-provided in the market place. These should be combined with a mix of advisory and institutional mechanisms, regulatory and legal measures, and economic instruments (levies/taxes) to correct negative externalities (Pretty et al., 2000). For the U.S., Tegtmeier and Duffy (2004) estimated the external costs of agricultural activities to range from \$5.7 to \$16.9 billion annually. Based on 168.8 million hectares of cropland in the United States, they calculated that the external costs varied from \$29.44 to \$95.68 per hectare. The authors argued for intervention to reassess and reform agricultural policy. Similar findings to those of the UK and U.S. were also found in a Swiss study by Pillet et al (2002). None of these studies provided a theoretical foundation for the measures they employed. Therefore, one objective of the current study is to provide an economic framework for the analysis.

Both the UK and U.S. studies focused mainly on agriculture's negative externalities, ignoring potential positive ones. Additionally, they only focused on externalities, and not on private costs and benefits (net value added) of agricultural production. In the current application to agriculture in the Netherlands, we consider not only negative but also positive externalities, as well as the direct net contribution of agriculture to the national economy.

Although there are a large number of partial assessments of farm externalities in the Netherlands (Jongeneel et al., 2005, 2012; PBL 2008a, 2008b, 2012; Bolt et al., 2008; Brink and van Grinsven, 2011), a clear integrated analysis of the external and internal costs and benefits of the agricultural sector as a whole is lacking. Thus, another aim of the current study is to fill that gap by synthesizing the results of various partial assessments. Although there is increasing awareness about the market and non-market impacts of agriculture in the ecosystems services literature (e.g., TEEB, 2014; INBO, 2014), there is a need for obtaining more accurate information than is currently available. Several estimates circulating in the ecosystems (but not economics) literature suggest that traditional evaluations relying on market measures largely underestimate the impact on ecosystems of human activities. The most notable of these are due to Costanza et al. (1997, 2014).[1] Values provided by these authors suggest that the economic value of food and fibre from agriculture are low relative to other ecosystem services that the land could provide, such as those of wetlands or estuaries. However, these estimates are based on limited empirical research. For example, Costanza et al.'s (1997) estimate of the ecosystem values for agriculture for the EU-27 is based on data from only one

[1] Costanza et al. (2014) estimate that the Earth's ecosystems have an annual value of \$142 trillion, or more than double global GDP. Since these measures are based on people's willingness to pay or compensation demanded, or on their actual expenditures (viz., hedonic pricing methods), the derived value of ecosystem services is clearly too high because it fails to take into account budget constraints. It is also too low because without any ecosystem services humans would go extinct – the actual value is therefore infinite. The problem is that decisions are not made on the bases of average (total) measures, but on costs and benefits at the margin – about whether the next ha in agriculture delivers more to society than it would have if it had been left to provide other services.

experimental arable farm in Denmark taken from Porter et al (2009). As a result, such information is not directly useful for policy purposes. Another aim of this study then is to calculate the economic impact of externalities associated with agriculture using multiple though still partial studies to obtain more precise estimates than are currently available, including information about the likely ranges of these estimates. Indirect effects occurring elsewhere in the supply chain (externalities generated in upstream and downstream markets) are beyond the scope of this study and are not considered.

The paper is organized as follows. In the next section, we provide the framework we use to measure positive and negative externalities, following in section 3 by an overview of the most important externalities associated with agriculture in the Netherlands. The main results for the Netherlands application are presented in section 4, followed by a discussion and concluding remarks in section 5.

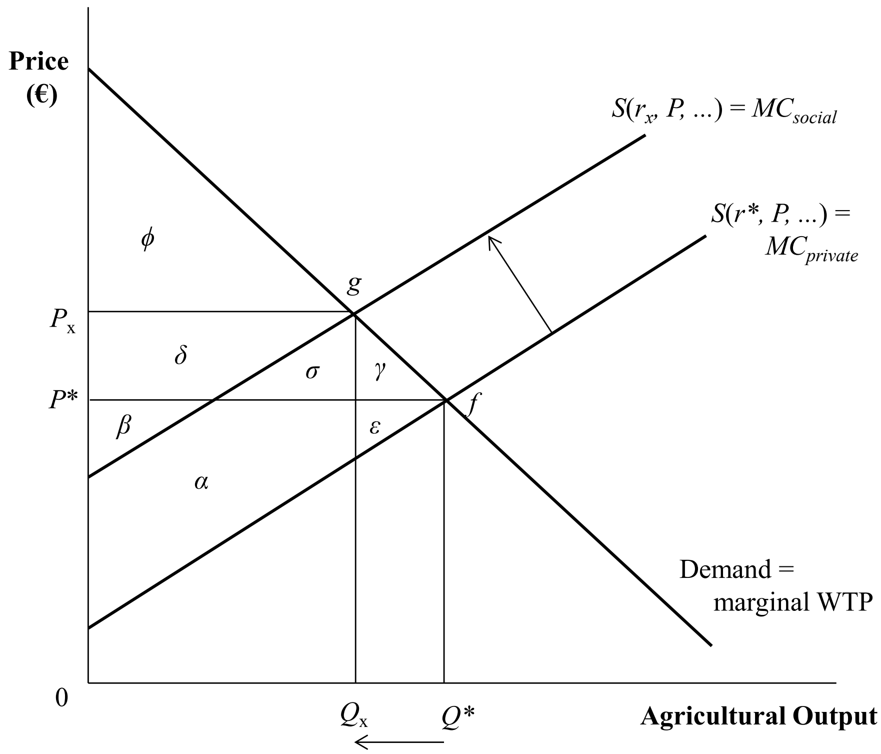
2. Methods: Analytical Framework

To justify the approach used in this study (and to provide context to the measures used in other studies), in this section an applied welfare economics framework for analysing both the positive and negative externalities associated with agriculture is provided (Just et al., 2004; van Kooten, 2016). To motivate the discussion, consider Figure 1. In the absence of incentives to address externality, the agricultural sector (whether it represents livestock producers or arable farms) will produce amount Q^* at price P^* in panel (a). This is where the demand and supply curves intersect. One can think of the demand function as the marginal willingness to pay (WTP) for the agricultural output (essentially food) and the supply function as the private marginal cost ($MC_{private}$) of producing that output.

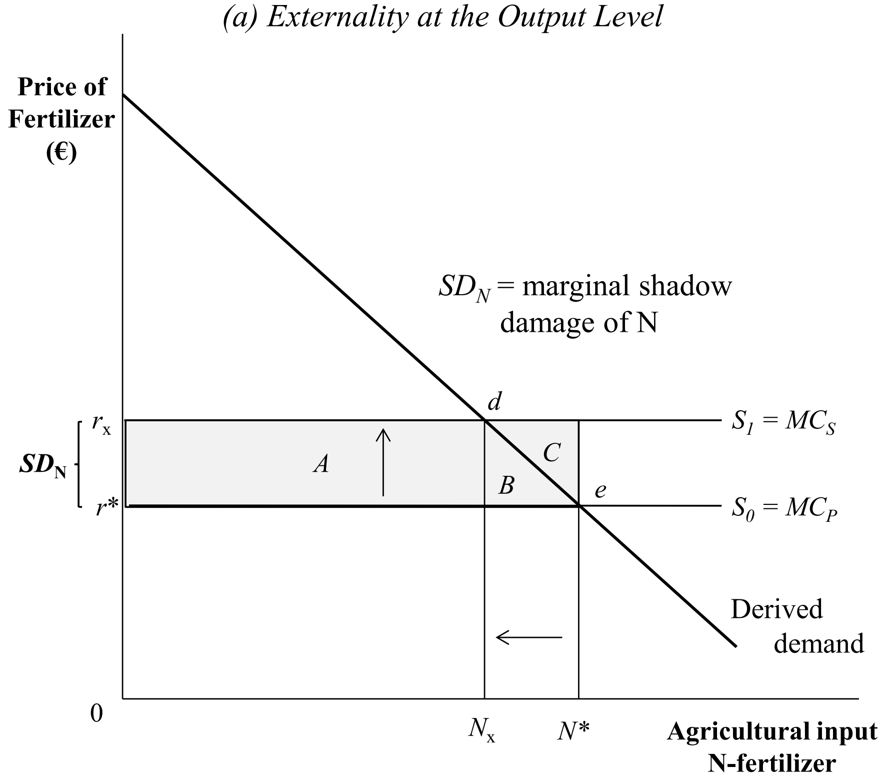
The private marginal cost function does not take into account the negative externalities associated with agricultural activities. It is the social marginal cost (MC_{social}) that takes into account both the private costs of farming plus their (negative) social impacts. This is illustrated in Figure 1(a), where the social equilibrium is Q_x, while the social price of food – the price that includes these spillover costs – is given by P_x.

What then constitutes the proper measure of the external costs? If external costs are ignored, consumers of agricultural commodities realize a consumer surplus given by area ($\phi+\delta+\sigma+\gamma$), while producers realize a quasi-rent (or producer surplus) to set against fixed costs that is given by area ($\alpha+\beta+\varepsilon$). After correcting for the externality, the new consumer surplus is area ϕ, while the quasi-rent is ($\beta+\delta$). That is, consumers are worse off by ($\delta+\sigma+\gamma$), while agricultural producers gain δ, which is a transfer from consumers, but producers lose area ($\alpha+\varepsilon$). The net loss to the agricultural sector is given by area ($\alpha+\varepsilon+\sigma+\gamma$) – the area between the MC_{social} and $MC_{private}$ functions bounded by the demand function. This is the cost to society of reducing agricultural externalities to their socially desirable level. Of course, the benefits to society of reducing these externalities presumably exceed these costs, although this is something determined in the political realm.

The problem here is this: How do we measure these costs given that we do not have all of the information to determine the demand and supply functions in Figure 1(a)? To do so, we must first realize that agricultural externalities occur upstream from the market for agricultural commodities depicted in Figure 1(a). It occurs at the farm level where too many inputs are employed than is socially desirable; that is, the farm sector employs too much fertilizer, pesticides, herbicides and land. It is the intensity of input use that causes negative spillovers (Boardman et al., 2006, p.85; Rosen and Gayer, 2008).



(a) Externality at the Output Level



(b) Negative Spillovers
Figure 1: Measuring the Costs of Externalities in Agriculture

It is the input markets that are of greatest relevance. Consider the market for nitrogen fertilizer in Figure 1(b). The demand function for fertilizer is derived from the agricultural sector's demand for fertilizer. The supply function for fertilizer is assumed to be infinitely elastic (horizontal supply), which is identical to assuming that the Dutch agricultural sector is a price taker in the (international) market for fertilizer.[2] In the absence of action to address negative externalities, N^* amount of fertilizer will be applied. At this level, excessive nitrogen is considered to enter ground and surface water. An appropriate way to incentivize farmers to take into account negative externalities is to tax chemical pollutants and/or GHG emissions, thereby shifting $S=MC_P$ (private MC) upwards to $S=MC_S$ (social MC), increasing the input price of N fertilizer from r^* to r_x, and reducing fertilizer use from N^* to N_x.

Given that society tends to support farm incomes, taxes are difficult to implement. Instead, governments will regulate the use of certain chemicals or specify a standard for water quality that must be met (e.g., 50 mg of N in groundwater), with a failure to meet the standard addressed using fines or stringent on-farm regulations. However, the result is the same: fertilizer use is limited to N_x, with the use of tradeable permits one option for ensuring that the restricted quantity is optimally allocated. Whatever mechanism is used, the marginal shadow damage resulting from fertilizer use equals $r_x–r^*$, which represents the cost of the externality.

An increase in the price of fertilizer causes the supply function in the agricultural output market to shift upwards and to the left, as indicated in Figure 1(a). Indeed, if excessive use of the fertilizer input was the sole cause of agricultural spillovers, then the increase in fertilizer price alone would reduce farm output from Q^* to Q_x.[3] Importantly for measurement purposes, the reduction in quasi-rent in the agricultural commodity market can be measured in the fertilizer market by the reduction in consumer surplus; that is, area ($\delta–\alpha–\varepsilon$) in Figure 1(a) is identical to area ($A+B$) in Figure 1(b) (see Just et al. 2004). If there were more inputs responsible for negative externalities in the agricultural sector, then it would be the sum of the lost consumer surplus areas in the various input markets that would equal the lost quasi-rent in the market for agricultural commodities.

Although not explicitly identified from a theoretical perspective, consider the welfare measure used in practice by Pretty et al. (2000), Tegtmeier and Duffy (2004), O'Neill (2007) and others, and employed here. This measure is given by the shaded area in Figure 1(b), or area ($A+B+C$). This area is equal to the shadow damage (cost) of fertilizer (SD_N) multiplied by the amount of fertilizer applied in the absence of policy to address the externality (N^*). This overstates the loss in quasi-rent by triangle C. Further, it neglects the loss

[2] This is a crucial assumption for welfare measurement because, if the supply function for inputs is upward sloping, then changes in upstream markets (e.g., petroleum refining, transportation, machinery production) will also need to be considered. This is avoided by the assumption of infinitely elastic supply functions in agricultural input markets. See van Kooten (2016) for further discussion.

[3] Supply in the commodity market is a function of the input price. Thus, the increase in the price of fertilizer shifts the supply curve in the commodity market upwards from $S(r^*, \ldots)$ to $S(r_x, \ldots)$.

in consumer surplus in the market for agricultural commodities; that is, it ignores the negative impact on consumers of an increase in food prices. In practice, the effect on consumers is deemed insignificant because expenditure on food is such a small component of income. In that case, the net loss to the agricultural sector is identical to the reduction in quasi-rent, which is identical to area (A+B), and is (over)estimated by shaded area C in Figure 1(b).[4] This then is a theoretically correct estimate of the cost to society of reducing agricultural externalities to their socially desirable level.

There are also positive externalities that need to be considered, some of which are related to the agricultural commodity market in the same way as fertilizer. However, unlike fertilizer, too little of the input is employed. For example, too little lime might be applied to lands that are acidic. Again assuming infinite elasticity of demand for agricultural output and an infinite elasticity of supply of lime, economic theory in this case would lead one to multiply the marginal (shadow) price by current lime use to obtain an estimate of the social benefit from expanding lime use. Unlike with a negative externality, this method underestimates the positive benefit.

In addition to the demand for food, citizens are willing to pay directly for some positive externalities – the visual amenities provided by the agricultural landscape (e.g., livestock grazing in a field, rapeseed in bloom), habitat and food for some species of birds, et cetera. In Figure 2, the horizontal axis measures environmental amenities with E^* equal to the environmental amenities associated with the level of agricultural output Q^* in Figure 1(a). Private demand for environmental services equals D_0, while society's demand is given by D_1. At private provision E^*, society's marginal value of the environmental services equals P', while the cost of producing them equals P^*. Society is willing to pay so that farmland provides more environmental services. In the absence of other considerations, it would be socially optimal to incentivize farmers to increase production of environmental services to E_{pos}. In that case, the added cost to agricultural producers is given by the area bounded by points E^*kbE_{pos}, while the benefit to society from expanding agricultural activities is given by area E^*abE_{pos}. The net benefit to society in this case is measured by the triangle kab. This area represents a measure of the welfare loss – the loss in society's wellbeing – of producing at Q^*.

[4] This implies infinite elasticity of demand (horizon demand) so that consumers are price takers. In that case only the change in quasi-rent (producers' welfare) needs to be measured (van Kooten 2016).

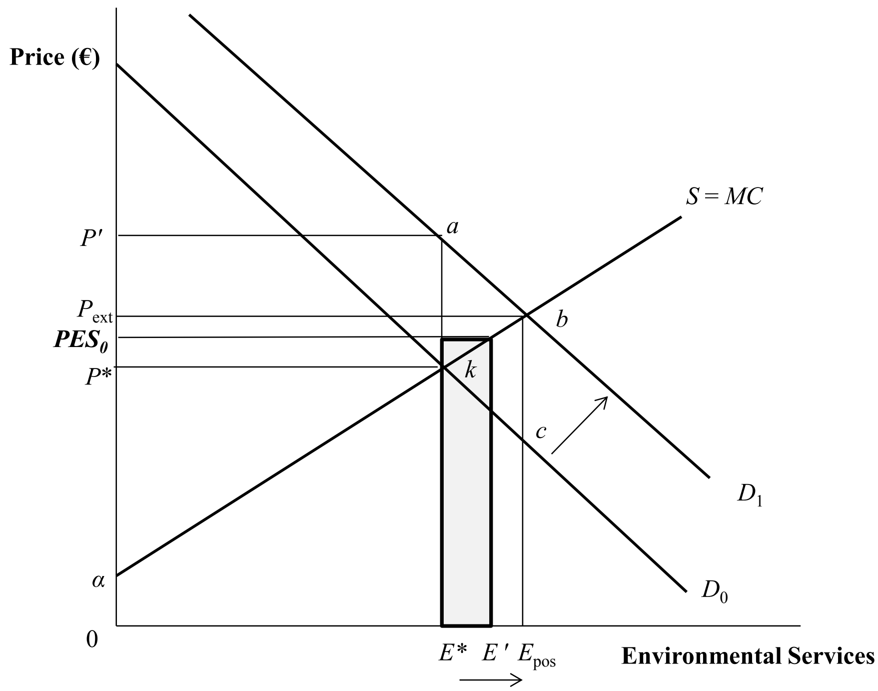


Figure 2: Agricultural Production and Environmental Services: Positive Spillovers

To get farmers to produce more environmental amenities, the government can pay agricultural landowners to modify their agronomic practices. Some examples include incentivizing farmers to delay mowing hayfields to facilitate breeding of certain meadow birds, plant trees to sequester carbon, or practice zero-till agriculture to prevent soil erosion and also store carbon. Payments for ecosystem services (PES) are increasingly used to incentivize landowners to take into account the WTP of citizens for environmental amenities or services. Of course, society could require farmers to implement certain practices in return for farm payments (known as cross compliance), thereby obtaining desirable levels of ecosystem services

Society's willingness to pay for positive externalities (Fig 2) is generally unknown and difficult to assess. However, society's preferences can be approximately determined from the political process. The policymaker can specify a minimum provision level that farmers have to attain, either because regulation forces them to do so or they provide it as a result of a PES or cross-compliance measure. Suppose the policymaker directly specifies a level of compensation for the environmental service given by PES_0. We then observe how much of the amenity is provided. Suppose we observe the payment increases environmental services from E^* to E'. Then an estimate of the benefit to society is given by the shaded area in Figure 2, although, with the exception of the shaded triangle lying above MC (which constitutes a quasi-rent or surplus to the producer), the payment essentially equals the cost of providing the service.[5] Of course, society's value is greater than PES_0 and society would also prefer more than E' (indeed, preferring E_{pos}).

The advantage of the forgoing approaches is that it enables the analyst to focus on the financial costs

[5] Notice that suppliers of environmental services always earn a surplus (or quasi-rent) when they receive a payment for environmental services; this payment is required to cover fixed costs, however.

(benefits) associated with reducing (increasing) the negative (positive) externality to a socially desirable level. Clearly, it allows the analyst to rely as much as possible on known data. However, there are several drawbacks to consider. First, it is still necessary to determine the marginal shadow damage of a pollutant or the value of an amenity. In the case of GHG emissions, the shadow price of carbon could be employed. Damage from nitrogen runoff could be measured using a non-market valuation method, such as hedonic pricing or a contingent valuation device. In any event, the analyst needs to know the value of the pollutant or amenity, and these values are not solely associated with agricultural activities. Fortunately, in many cases these values are available in the literature.

Second, the approach employed here and in previous studies under- or overestimates the desired welfare measure by the triangles identified above. In the case of externality, and assuming the marginal shadow damages of the externality have been correctly estimated, our approach will overestimate negative externalities and underestimate positive ones. Given the high degree of uncertainty regarding estimates of shadow damages, the measurement error is likely relatively unimportant.

Third, the assumption that supply functions in input markets are infinitely elastic is unavoidable, but probably realistic for most markets but not all. With regard to the production of chemicals (pesticides, herbicides and fertilizers), this will depend on the extent to which the inputs into these products are transferable to the production of other commodities (e.g., plastics, petroleum products, etc.). The assumption that the demand for agricultural commodities is infinitely elastic is perhaps more realistic. This is likely truer for developed than developing countries, but, again, this assumption is unavoidable.

Finally, our method for estimating the externality costs implicitly assumes constant marginal abatement costs. In practice, however, various measures are used to cope with a single externality. For example, the EU's Water Framework Directive (WFD) includes a variety of measures, such as wet buffer zones along streams, improvement of water clearing facilities, and zones with no organic manure application. Often the mix of measures differs depending on specific local circumstances, and measures differ not only with respect to their effectiveness but also with respect to their costs (van Soesbergen et al., 2007). The linear cost approximations using marginal costs as evaluated here might then underestimate the true costs.

Although we have a theoretical foundation upon which to base our measurements, we also validate our approach by comparing our results against those from other studies, especially studies that employ different methods. By relying on other studies, we are able to get more detail and refinement into the analysis, while also addressing the attribution problem: What measures and thus what costs should be linked to the reduction of which negative externality or the improvement of which positive externality? As the information used in our analysis come from various studies that focus on specific pollutants or amenities rather than on specific externalities, we have to determine how to fit the data into the measurement framework that we employ while avoiding double counting.

3. Dutch Agriculture and Externalities

Before estimating the many costs and benefits associated with agriculture, it is important to be aware of the different impacts that the agricultural sector has on the environment in the Netherlands. Dutch agriculture comprises two main parts: animal production and crop production. Each sector has different impacts on the environment, which for current purposes, is subdivided into (1) soil, (2) water and (3) atmosphere.

Both livestock and arable (crop) farms have an impact on the soil. The manure from cows, sheep, goats, pigs, poultry and rabbits is spread on the land, causing excessive deposits of nitrogen (N) that gets converted to nitrates (NO_3), phosphates (P) and zoonosis (a disease that is transferable from animals to humans), while crop production employs pesticides and fertilizers that negatively impact the soil (RIVM, 2013). These forms of chemical pollution of soil adversely affect plant and animal biodiversity. Likewise, changes in land use and how land is managed also impact the composition of the soil, thereby affecting its future productivity and biodiversity. Finally, certain land-use practices (e.g., tree planting, zero tillage and permanent grasslands) can sequester carbon from the atmosphere, thereby mitigating climate change.

Livestock enterprises and arable farms have an impact on water quality, primarily because chemicals that first enter the soil subsequently leach into groundwater or runoff into surface water. P and N can adversely affect lakes making them less suitable for supporting aquatic ecosystems, while polluted water can have a negative effect on biodiversity more generally. Chemicals in ground (and surface) water can also affect human health. To improve water quality involves costs, with an estimate of these costs providing information about the negative externality effects of agricultural activities.

Livestock operations emit methane (CH_4), CO_2, nitrous oxide (N_2O), sulphur dioxide (SO_2) and ammonia (NH_3) to the atmosphere, while arable farms emit CO_2 and nitrogen (see RIVM, 2015). The annual CO_2 flux from agricultural activities is an important component of global warming that can be measured using information on the shadow price of carbon. In addition to CO_2, pollution from N_2O and SO_2 is a concern. N_2O rapidly oxidizes to become nitrogen dioxide (NO_2), which results in smog (a smelly, yellow-brown haze), while SO_2 leads to acidification. To determine the external impact of these pollutants on the atmosphere requires calculation of emissions by livestock sector and crop type.

The impacts of agriculture are more extensive than the traditional environmental impacts on soil, water quality and the atmosphere. They also concern the impacts on biodiversity, wildlife habitat, landscapes, animal welfare, food security and human health (Yrjölä and Kola, 2001). Farming reduces habitat for some animals (large ungulates), but creates habitat for others (meadow birds); it destroys some amenities (wooded areas that store carbon) while providing new ones (visually appealing landscapes); it eliminates some wetlands that function to filter water and mitigate flooding, but the in-filling of such wetlands destroys mosquito habitat thereby improving human health. Agricultural policies affect land management and use, thereby incentivizing activities that have both negative and positive externality effects.

In Figures 3 and 4, we provide an overview of the evolution of some key indicators of the externalities associated with Dutch agriculture. From Figure 3, it is clear that releases of nitrates and phosphates into surface waters have fallen continuously since the mid-1990s, primarily as a direct result of legislation.[6] The use of pesticides was reduced by about 60% during the period 1990-2003 after which use stabilized, although in more recent years it even rose slightly. Likewise, emissions of greenhouse gasses fell by about 20% during 1995-2005, after which they stabilized or even increased slightly (Fig 4). As regards to biodiversity, one indicator, the number of meadow birds, declined at an average annual of about 2% (Fig 4).

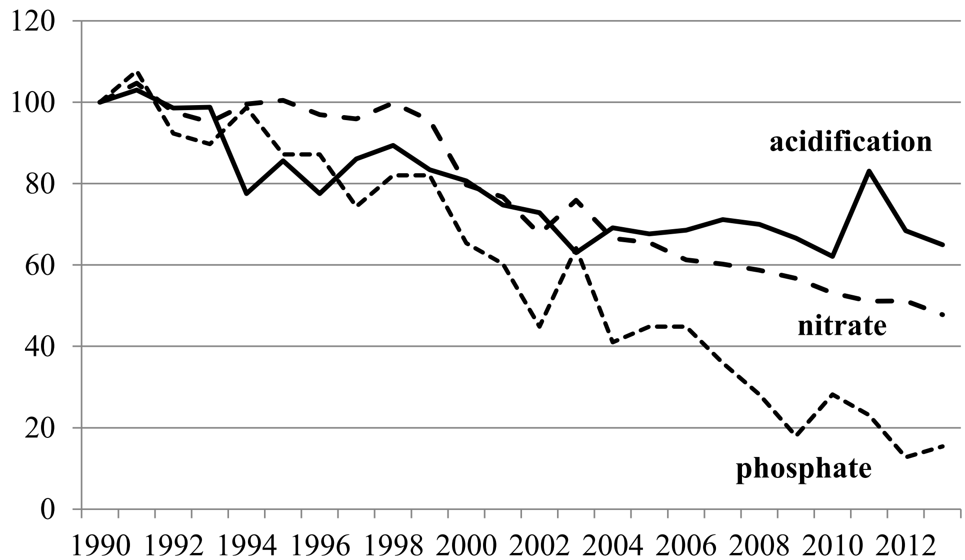


Figure 3: Indicators of Agricultural Externalities, Acidification and Nitrate and Phosphate Use, 1990-2013 (Index 1990 = 100)

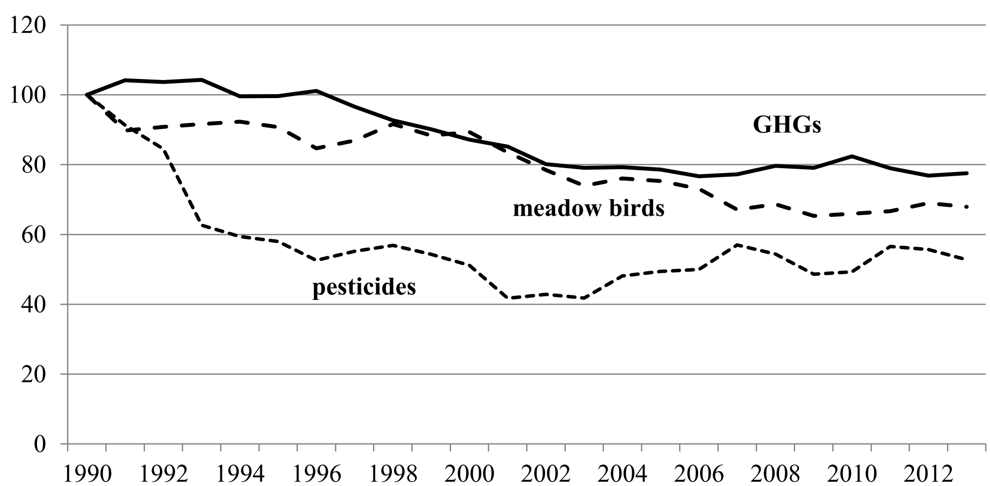


Figure 4: Indicators of Agricultural Externalities, Greenhouse Gas Emissions, Numbers of Meadow Birds and Pesticide Use, 1990-2013 (Index 1990 = 100)

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[6] Van Puijenbroek et al. (2014) provide information about the improved performance with respect to eutrophication of surface waters.

4. Results

What is the contribution of Dutch agriculture to society's wellbeing? In this section, we provide estimates based on the period 2005-2102. Data came from various sources, especially from databases and reports available at the Agricultural Economics Institute (Landbouw Economisch Instituut, LEI) and the Dutch Environmental Agency (Planbureau voor de Leefomgeving, PBL, but now DEA) in The Hague, although this still required an extensive data search. (More details on these sources are provided in the Appendix to this paper.) A summary overview of the resulting estimates of the costs and benefits of the agricultural sector to the Netherlands is provided in Table 1. The magnitudes of the external costs associated with agriculture were determined using the approximation method discussed in conjunction with Figure 3; these are equivalent to about 35% of the value added, or nearly 8% of production value. The estimated values of the external benefits are low relative to the external costs. Finally, some alternative measures of the externality costs are provided in the last column of the table.

Total benefits due to agricultural production, according to available data and research in the Netherlands, are calculated to be €10,604 million a year, including an estimate of the (net) external benefits of €263 million. Total annual costs are calculated to be €1,868 million. By subtracting the total costs from the total benefits, the average total net benefits from agriculture in the Netherlands are €8,736 million per year for the period 2005 until 2012. Nonetheless, negative external costs equal €988 per ha of arable and horticulture land and permanent pasture. More details on various costs are provided in the next paragraphs.

4.1 External costs to soil

A specific aspect to consider with respect to the soil is emissions from peat soils and the decline in the level of these soils.

<u>4.1(a) CO_2 emissions from peat soils</u>: In the Western part of the Dutch delta, peat soils are used for agriculture by artificially lowering the surface water level, with water levels ranging from 30 to 90 cm below the surface (van den Born et al., 2016). As a result, the soil oxidizes thereby leading to CO_2 emissions and a steady decline in soil depth of about 0.8 cm per annum. According to a recent estimate, the annual CO_2 equivalent of 4.2 Mt CO_2 are released, of which 3.4 Mt is related to agriculture, representing about 13% of the total GHG emissions of Dutch agriculture (Coenen et al, 2014; see also section 4.2). We assume a shadow price of carbon of €16/tCO_{2e}, which is considered to be on the high side (Bickel and Friedrich, 2005; Appendix Table A.1). Then the associated annual cost is €54.8 million (= 3.4 × €16/tCO_2). See Table A1 for details on CO_2 prices.

Table 1: Annual Average Total Social Costs and Social Benefits Attributable to Dutch Agriculture, 2005-2012 (million €)

Cost category	Value	Benefit category	Value
Negative Externalities		Positive Externalities	
Soil			
1a. CO_2 emissions peat soils	€ 55	4a. Agro-environmental services	€ 60
1b. Water management	€ 10	4b. Other non-commodity output	€ 203
1c. Soil organic matter, erosion, soil compaction	€ 3	Subtotal	€ 263
Subtotal soil	€ 68		
Water		Direct Production Benefits	
2a. Nitrogen total	€ 146	5a. Animal production	€ 4,075
2b. Phosphate total	€ 43	5b. Crop production	€ 1,272
2c. Pesticides	€ 144	5c. Horticulture production	€ 4,994
2d. Eutrophication	€ 219	Subtotal direct benefits	€ 10,341
Subtotal water	€ 552		
Air			
3a. Greenhouse gasses (CO_{2eq})	€ 416		
3b. Acidification (NO_x, SO_2)	€ 429		
3c. Emissions of ammonia	€ 403		
Subtotal air	€ 1,248		
TOTAL COSTS	€ 1,868	TOTAL BENEFITS	€ 10,604
Excess of benefits over costs	€ 8,736		
	€ 10,604		€ 10,604

Source: Own calculations based on data for 2005-2012 or closest approximation to this period when data were missing.

4.1(b) Water management: The additional costs associated with dewatering peat soils consists of costs to pump the water into rivers, costs associated with damming up the water, and costs for maintaining and upgrading dykes. The latter costs are the most important ones and amount to about €50/ha, while pumping and damming costs account for about €10/ha. The total peat area at risk is about 200,000 hectares, so the total annual costs are €11.9 million (calculations based on van den Born et al, 2016). It has been estimated that 81% of these costs are related to agriculture. The net external cost that need still be taken into account is then €9.6 million.

4.1(c) Soil organic matter, erosion and soil compaction: To determine the damage to the soil's natural capital, a distinction is made between off-site damage caused by soil erosion and loss of organic matter, and CO_2 emissions (Kuhlman et al, 2010). A healthy soil is vital for agriculture, but agricultural practices result in soil erosion through tillage, cultivation and land left without cover after harvest (Tegtmeier and Duffy, 2004). Because the Netherlands is a flat country, agricultural land is not prone to high rates of soil erosion (exceptions might include Limburg province, the Bollenstreek area and the Veenkoloniën area), and further costs are ignored. In addition, there are costs associated with eutrophication resulting from runoff of N and P into surface water (see also section 4.2(d)) and soil compaction mainly caused by heavy machinery. Compacted soils have a reduced buffering capacity that leads to increased leaching of N and greater N_2O emissions to the air (which are included under air pollution so as to avoid double counting). Considering soil compaction and taking the conservative estimate from the range provided by Kuhlman et al. (2010, p.47), the externality costs of soil compaction amount to €2.70/ha. Then assuming that the light sandy and sandy soils are particularly sensitive to compaction, so 50% of 2.1 million ha is affect (van den Akker and Hoogland, 2011), the external costs are estimated to be about €2.8 million (= ½ × 2.1 million ha × €2.70/ha).

Soil compaction also reduces crop productivity, perhaps lowering yields by some 2.5%. However, the yield reduction is already taken into account in the direct benefit estimate of agriculture (see item 5b in Table 1 and discussion below), and is not measured here (Kuhlman et al., 2010). The same is true of organic matter loss: this shows up in lost productivity and in increased CO_2 emissions (as organic matter decays) that are accounted for below. Finally, soil salinization is an externality that is very difficult to quantify but could be a more serious problem in the future. Overall, our provisional estimates of the costs related to soil degradation are negligible, or taken into account via its negative effect on crop yields.

4.2 External costs to water

The second cost category is the damage to water resources. Farm wastes, organic matter, microorganisms, pesticides, nutrients and chemical fertilizers pollute ground and surface waters (Pretty et al., 2000). These pollutants are rarely discharged directly into surface waters as a result of soil erosion, but rainwater causes them to leach into the soil and then into groundwater. Thus, they are non-point source pollutants. Water delivery companies have to comply with the EU's drinking water standards (European Commission, 2013). Water delivery companies incur costs to comply with this EU policy. Besides several substances in the water, agricultural activities cause eutrophication and pollution incidents.

4.2(a) Nitrogen Treatment: Nitrogen enters drinking water from the mineralisation of organic N in the soil, fertilisers and livestock wastes, and from atmospheric depositions (Pretty et al., 2000). Nitrogen can leach into groundwater sources or be carried by soil particles into surface waters via runoff. Although the amount of N in surface waters declined between 2005 and 2012, N still impairs aquatic ecosystems and is a human health concern (Tegtmeier and Duffy, 2004). On average, agriculture contributed 56.0 million kg nitrate annually to surface water during 2005-21012 (CBS, n.d). Agriculture's share of total N emissions was 60% during this period. Expenditures by water companies on nitrogen removal amounted to €2.60 per kg N (de Blaeij et al., 2013). Based on this information, we estimate a total a negative impact from N pollution of €145.6 million (= 56.0 million kg × €2.60/kg).

4.2(b) Phosphate Treatment: In the Netherlands, most soils are satiated with phosphate due to years of over-fertilization and manure disposal. During 2000-2005, agriculture was responsible for the annual release of 4.2 million kg of phosphate into surface waters, or 13% of total phosphate disposition (CBS, n.d.). The costs associated with the removal of phosphate from the water are estimated to be €10.30 per kg P (de Blaeij et al., 2013). The average annual costs are estimated to be €42.7 million (= 4.2 million kg × €10.30/kg).

4.2(c) Pesticide Treatment: Pesticides from agriculture enter surface and groundwater systems through runoff and leaching, posing a risk to aquatic life and human health (Tegtmeier and Duffy, 2004). Buurma et al. (2013) estimated the costs to agricultural producers in different sectors for reducing pesticide use. These costs are used to estimate the total externality cost of treating pesticides in the Dutch agricultural sector. Estimated costs to comply with the emission norms for an arable farm are estimated to be €2,250 annually, while those for a livestock enterprise are €2,400 per year (Buurma et al., 2013). Based on the total number of farms of each type in the Netherlands, an estimate of the total costs of avoiding pesticide contamination is €143.7 million per year. Notice that these are avoidance costs based on the precautionary principle, and would not be based on the economic notion that some amount of pesticide use below current levels of application is optimal.

4.2(d) Eutrophication: Freshwater eutrophication (nutrient enrichment) is an externality leading to a reduction in the supply of ecosystem services. Nutrient enrichment leads to (toxic) algae blooms or, more generally, hypoxia (depletion of oxygen) that harms aquatic life and reduces biodiversity (e.g., Sutton et al., 2011). Some aquatic species such as eel are of commercial interest; swimming and other recreational uses of water are harmed by the presence of algae blooms. The Dutch Ministry of Transport, Public Works and Water (VWS, 2006) examined scenarios that could best achieve their policy objectives for water quality. The Ministry calculated that the discounted cost of eutrophication mitigation measures over an 18-year period was €5,014 million. Assuming agricultural activities contributed 60% of the chemicals leading to eutrophication and upon discounting (using a rate of 3%), the annual cost of mitigating eutrophication of surface waters is estimated to be €218.7 million.

4.2(e) Summary: Total damage to water resources due to agricultural production, according to available research in the Netherlands, is estimated in this study to be €550.7 million per year. The PBL (2008b) estimates the annual costs of existing and new measures related to the Water Framework Directive, whose main aim is to improve water quality, to be €390 million. Assuming agriculture's share in the various pollutants leading to hypoxia is 60%, the costs attributed to agriculture would be €234 million. Moxey (2012, p.15) estimates that the annual costs of nitrate and phosphate pollution for the Netherlands to range between €403 million and €754 million, resulting in annual costs of €241-452 million based on agriculture's assumed contribution. Our estimates are somewhat higher than those from these detailed studies.

Table 1 does not provide a complete review of all impacts on water by agricultural production. This is because costs related to the measurement, monitoring and governance related to pesticides and nutrients, eutrophication costs and the costs incurred by zoonosis in sources of drinking water are not included.

4.3 Externality Costs of Atmospheric Pollutants and CO_2

The third cost category concerns the release of pollutants and CO_2 to the atmosphere. Agriculture contributes to atmospheric pollution through the emissions of five gases: methane from livestock, nitrogen oxide from fertilisers, ammonia from livestock wastes and some fertilisers, carbon dioxide from fossil fuel consumption and loss of soil carbon, and sulphur dioxide from farms. These gases contribute to global warming, acidification of soils and water, eutrophication and ozone loss in the stratosphere (Pretty et al., 2000). The agricultural sector contributes about two-thirds of total Dutch greenhouse gas emissions.[7]

4.3(a) Emissions of greenhouse gasses: For the period 2005-2012, Dutch agricultural emissions of CO_2, CH_4 and N_2O averaged 7.4, 12.2 and 6.2 Mt CO_{2e} per annum. The total annual average of 25.8 Mt CO_{2e} includes the CO_2 emissions from horticulture, but includes those from peat soils.[8] Again, assuming a shadow price of carbon of €16/tCO_{2e}, or €0.016 per kg CO_{2e}, the annual costs attributed to GHG emissions is estimated to be €416 million (= 25.8 mil tonnes × €16/t).

4.3(b) SO_2 Emissions (acidification): Next to emissions from transportation and industry, agricultural emissions of SO_2 play an important role in acidification that damages trees and other organisms. Average annual emissions of SO_2 amount to 107.3 million kg. The marginal costs of acidification are estimated to be €4 per kg SO_2 (Appendix Table A.1), so that annual damage from acidification amounts to €429.4 million (= 107.3 mil kg × €4/kg).

4.3(c) Ammonia: Because the LEI (2013) tracks all animals in the Netherlands, it calculates the total ammonia produced annually by the Dutch agricultural sector. The shadow marginal costs of ammonia emissions are retrieved from a study by Walter et al. (2008), who estimated the costs of restoring the damage caused by ammonia to the natural environment. The restoration costs are based on the least expensive means of avoiding the damages. The estimated restoration costs are €3.14 per kg of ammonia emissions for the Netherlands (Walter et al., 2008). Given an estimated 128.2 million kg of ammonia emissions from manure, the annual cost of such emissions costs are estimated to be €402.6 million (= 128.2 mil kg × €3.14/kg).

4.3(d) Summary: According to available data for the Netherlands, total damage to the atmosphere due to agricultural production amounts to some €1,248.0 million annually. According to AEA (2011), the damage to buildings and other structures of air pollution in the Netherlands is estimated to be about €3.4 billion (medium scenario). Accounting for agriculture's 5% share of total emissions would lead to an annual cost

[7] Data on GHG emissions, nitrogen and phosphate use, and other pollutants are available from the Dutch Environmental Agency (http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl0099-Emissies-naar-lucht-door-de-land--en-tuinbouw.html?i=11-60 [accessed 22 March, 2016] and http://www.agrimatie.nl/Data.aspx (in Dutch) [accessed 17 January 2016]). The calculation of greenhouse gas emissions is in accordance with IPCC standards.

[8] The average annual contribution of horticulture to Dutch CO_2 emissions for the period 2005-2012 was 5.3 Mt CO_2, or about 20% in agriculture's overall GHG emissions. Horticulture's GHG emissions have been falling; in 2013 emissions were 4.9 Mt CO_2, about 20% lower than in 2005. Further, rather than only consuming energy, the Dutch horticultural sector now produces energy, contributing about 10% of total Dutch energy production. The CO_2 emissions associated with the horticulture's energy production (currently about 1.9 Mt CO_2) have been left out of the analysis and are treated as unrelated to agriculture.

attributable to agriculture of €170 million. A recent PBL (2012) study suggests that, depending on the strictness of the chosen emissions (revised) benchmark, about €18 to €40 million might need to be added to our values to account for costs attributable to agriculture. If costs to human health are also included the impact would be somewhat higher, some 3.5% according to Tegtmeier and Duffy (2004). We do not include human health impacts, because, with the exception of pesticide use, the main human health impacts occur as a result of downstream food processing, an activity not taken into account in this study.

Although there are many other positive external benefits (as briefly discussed in previous sections), we provided estimates only for a select set of positive external benefits and only one positive externality (biodiversity). As a result the positive external benefits are likely to be still highly underestimated.

4.4 Positive External Benefits

In addition to the direct benefits from agriculture, namely, those related to its main function of producing food, feed and biomass, the sector also provides positive external benefits. Some of the positive benefits relate to environmental goods and services, such as biodiversity preservation, but there are other green services that are not usually considered pure externalities since they are marketable outputs, such as agro tourism. As with externalities, we are concerned only with flows and not stocks.

In Table 2, we provide details concerning the gross value and value added for four non-commodity outputs. The values are for 2011 as opposed to an average over the period 2005-2012 simply because the extent of these activities has increased rapidly in recent years, so the average under-represents their importance. The total value of the positive external benefits, in terms of what taxpayers (agro-environmental services) and consumers (marketed non-commodity services) are actually willing to pay is €425 million. However, since there is a cost to producing these gross benefits (see also Figure 3), it is their net contribution to the sector's income (or value added) that is important. The value added is estimated to be €263 million. The separate categories are discussed in more detail in what follows.

Table 2: External Annual Benefits from Dutch Agriculture (million euro)

Benefit/cost category	Gross value (€)	Factor income share (%)	Value added (€)
Biodiversity and landscape			
Agro-environmental services	71	85	60
Grazing services and amenities	*pm*[a]	0	0
Subtotal biodiversity benefits	71		60
Other non-commodity benefits			
Day nursery activities	20	75	15
Care farming	80	75	60
On-farm selling	98	35	34
Agro tourism	156	60	94
Subtotal non commodity benefits	354		203
TOTAL	**425**		**263**

[a] *Pro memori*: this needs to be taken into account but has not been monetized.
Source: Authors' calculations based on van der Meulen et al. (2014) and the Dutch Ministry of Economic Affairs (personal communication 17-10-2014).

4.4(a) Agro-environmental services: Agriculture delivers services such as biodiversity conservation and wildlife habitat, visual amenities, agro-tourism services, et cetera (see Pretty et al., 2000, for an expanded discussion). The benefit to society of these services is estimated according to the procedure discussed with respect to Figure 3(b). The annual expenditure by the government on agro-environmental services based on the Dutch population for 2007-2013 is about €70 million, which includes co-financing and the national top-up to EU payments for biodiversity and landscape (see measure 214 of the EU's RDP). The area affected by agro-environmental services is estimated to be about 59,000 ha, and the average payment per hectare is €1,200 (van der Meulen et al., 2014). The benefit or income generated for the primary production factors is about €60 million. The provision of agro-environmental services may include other costs than the non-factor costs that are taken into account in the value-added estimate (e.g., forgone agricultural output due to reductions in yield or the land input). However, these latter costs are already implicitly taken into account in the estimate of direct benefits (value added) of agriculture (see further details below). The delivery of these services mainly comes from dairy, beef and sheep farms that graze animals (participation rate 24%) and arable farms (participation rate 9%).

Farms that graze animals (e.g., suckler cows, sheep) provide services to nature conservation organisations because land is kept in pasture and not tilled. Further benefits can be realized if grazing is restricted to certain periods (to protect breeding birds that build nests on the ground) and/or grazing intensity is restricted (often to less than 1.4 livestock units per ha) Jongeneel and Smit (2013, p.59) estimate that about 38,000 livestock units are grazed in nature areas, but that the gross margins to milk cows and sheep in these areas are negative or low. For this reason the net value added from the provision of grazing services has not been monetized.

Citizens value viewing dairy cows grazing in meadows. To preserve outdoor grazing, about 65 parties signed an "Outdoor Grazing Covenant" in 2012.[9] Dairy processors provide financial incentives to farmers who graze cows, with the payment currently €0.01 per litre of milk for cows that graze at least 120 days per year for more than 6 hours per day. Dairy products from these cows receive a grazing label (weidemelk) and sell at a premium. For 2005-2012, an estimated 70% of all cows met the grazing standard, accounting for 7.8 billion litres of milk (Reijs et al., 2013). The value of this amenity is then €78.4 million (=7,840 mil litres × €0.01/litre).[10] Since this amount is already included in agricultural value added, however, it is not included as a separate benefit.

4.4(b) Other non-commodity output: *Care farming* is a valued activity that caters to people who are physically or mentally challenged or disabled and, as part of their therapy, spend time on a farm where they 'participate' in farm life, interact with people and (importantly) with animals, enjoy an agro-natural environment, and may even contribute to work activities on the farm. The number of care farms has increased considerably, with growth rates nearing as 15% per annum over the last decade. The value associated with this endeavour is estimated to be worth €80 million; in addition, day care and nursery activities on farms generate an annual value of about €20 million (van der Meulen et al., 2014). The provision of these services involves about €25 million of (non-factor) costs, implying a value-added contribution of about €75 million.

Agro tourism does not constitute an externality because tourism services are traded in established markets. However, it constitutes a non-agricultural output. Based on farm accountancy data, the Dutch agricultural sector delivers agro-tourism services (camping sites, on-farm recreation) worth some €156 million (van der Meulen et al., 2014). Although only a small minority of farms participate in this market, the net contribution to agriculture's sectoral income is estimated to be €94 million.

4.5 Direct benefits

The average annual value of Dutch agricultural production for the period 2005-2012 was €23,831 million. The direct benefit, however, is the value added generated by the sector. An activity-based approach was used to determine value added. For each subsector of agriculture, the value added was calculated by subtracting all non-factor costs from total revenues. The amount that remains is a proxy for the remuneration to the primary factors of production. Using this approach ensures that the benefits associated with non-commodity outputs are excluded. However, since participation in agro-environmental schemes might have some impact on farm production (output forgone) and this method is based on empirically observed yields, some of these costs

[9] This initiative of the Duurzame Zuivelketen (Sustainable Dairy Chain; see http://www.duurzamezuivelketen.nl/en/grazing) includes dairy farmers' organisations, upscale supply chain parties and service providers (e.g., banks, feed suppliers, auditors, veterinarians and stockbreeders), retail organisations, dairy cooperatives, civic society organisations (e.g., animal welfare and environmental organisations), government institutions, researchers, and educators.

[10] It is interesting to note that this private initiative is market driven and aimed at a specific externality that the CAP also seeks to address via the second pillar. Yet, the voluntary program payment of €78 million exceeds the entire CAP second pillar payment to the Netherlands for environmental purposes, with the CAP payment accompanied by high overhead and transaction costs.

(and their negative impact on the direct benefits from agriculture) will already have been accounted for in our estimate. All data on the number of animals and production of crops are retrieved from the LEI and CBS databases (including Agricultural Accounts and FADN-data). The results are presented in Table 3.

Table 3: Direct Benefits from Agriculture in the Netherlands (€ millions)

Benefit/ cost category	Average benefit (€)	Minimum (€)	Maximum (€)
Animal production			
Dairy and cattle	2,924	2,135	3,250
Pigs	656	627	678
Poultry and eggs	374	341	403
Other animals	8	6	9
Subtotal animals	*4,075*	*3,209*	*4,468*
Crop production			
Cereals and oilseeds[a]	42	90	280
Root crops[b]	1,230	851	1,247
Subtotal crops	*1,272*	*941*	*1,527*
Horticulture[c]	4,994	4,856	5,518
TOTAL	10,341	9,006	11,513

[a] Includes wheat, barley, maize, rye, oats and rapeseed.
[b] Includes potatoes, starch potatoes, seed potatoes, sugar beets, fodder and seed onions.
[c] Includes vegetables, mushrooms, flowers, and ornamentals.
Source: CBS, Agricultural Accounts (various years) for total value added (evaluated at market prices) and own calculations to derive the amounts by subsector.

The total benefit accruing to livestock enterprises is estimated to be €4,075 million. The most important livestock sectors in the Netherlands are dairy, pigs and poultry; these provide a direct average annual benefit of €3,954 million (excluding cattle and eggs). Arable farms provide total benefits of €1,272 million, based on available data for the Netherlands. As shown in Table 2, dairy plays a central role in the livestock sector, while root crops are predominant in arable production. Horticulture provides a total benefit of €4,994 million (share in total benefits of agriculture is 48%). The estimates in the table are of a similar magnitude as those calculated following a factor input approach (see van der Meulen et al., 2013). Total direct benefits amount to €10.341 billion, or about €5,611/ha including horticulture (€2,795/ha excluding horticulture).

5. Discussion and Conclusions

In this paper, we provided an analysis of the quantifiable direct and indirect costs and benefits of the Dutch agricultural sector. In doing so, we developed a model grounded in applied welfare economic theory that was then employed to provide estimates of the externality costs of agricultural activities. Results indicated that the agricultural sector imposed external costs on the rest of society that amounted to about 17.5 percent of value added in agriculture, and that external costs were much higher than the external benefits (2.5% of value added).

The impacts of externalities differ across countries partly because the role and importance of agriculture vary across countries. Our estimates of the annual externality costs associated with agriculture in the Netherlands equal some €988.4/ha (= €1,868 mil/1.89 mil ha). This compares to €423 (£208) per ha of arable and permanent pasture in the UK (Pretty et al., 2000) and €19.74 to €64.14 per cropland ha in the U.S. (Tegtmeier and Duffy, 2004). On the other hand, the agricultural sector provides positive external benefits related to the production of environmental services and non-agricultural 'products' that have a gross value of €425 million (Table 2), or €224.9/ha (=€425 mil/1.89 mil ha), and net value of €263 million, or €139.2/ha. The net external cost imposed by Dutch agricultural activities is then equal to €849.2/ha (= €988.4/ha – €139.2/ha). Finally, the average annual overall benefit (including positive and negative externalities) amounts to €8,736 million (Table 1), or net benefit of €4,622.2/ha for the 1.89 million ha of agricultural land in the Netherlands. While all numbers have a considerable margin of uncertainty, the large difference between Dutch and other country values clearly reflects the intensity of agricultural production in the Netherlands relative to that in other countries.

This study constitutes a first attempt to come to grips with the externality or environmental impacts of Dutch agriculture on society. We find that these costs are substantial. What are the policy implications of our findings? Clearly, we do not suggest that Dutch agricultural activities should cease, because this would confuse average (total) and marginal aspects. Rather, to the extent that our results pertain to land use, the results suggest that there might be some room to scale back the intensity of land use in the agricultural sector. This is already partly being done. Greening of the CAP, for example, requires farms to plant a greater variety of crops and to create ecological focus areas (5% of the land). Cross compliance requires that landowners meet certain standards of animal welfare and land stewardship as a condition for receiving government support payments. After the abolition of the milk quota in April 2015, the Nitrate Directive serves to curb growth in dairy production. In addition to these 'red' ticket items, farmers are incentivized ('green' ticket) to produce certain positive environmental amenities that citizens desire (e.g., farmers deliver green services via their participation in agro-environmental and climate schemes in exchange for government payments). While future research should address non-market values (see PBL, 2008) and health effects, for example, these extra considerations would only reinforce the current course of CAP reforms and Dutch measures to reduce externalities through improved land use management. Perhaps some decades in the future these values will be more crucial in guiding policy than currently.

While the approach employed in this study is solidly grounded in economic theory, it is not without problems. First, the underlying data that inform our estimates of the externality costs come from various studies which employed economic techniques ranging from one based on revealed preference (e.g., hedonic pricing) methods to integrated assessment models (e.g., shadow prices for CO_2) and contingent valuation devices (e.g., estimates of costs of air pollution). Uncertainty regarding such damage estimates is ultimately reflected in our estimates of the externality costs of agriculture. For example, we employed a carbon price of €16/tCO_2 as explained in Table A.1. If a carbon price of €50/tCO_2 were used instead, externality costs would rise from €1,868 million to €2,321 million, then accounting for 22.4% of agricultural value added. However, even if the price of carbon were at this higher level, it would constitute an overestimate because one would need to subtract from the externality estimate the damages from CO_{2e} emissions if the land was used in an activity other than agriculture, something not addressed in the current study.

Further, marginal abatement costs were assumed to be constant, but in practice they are likely to rise as the level of abatement increases. This could lead to an underestimate of the real costs of the externality. Moreover, our approach might underestimate the complexity and multiplicity of measures that are usually taken, each having its own impacts and costs. We partly address this issue by comparing our results to those of other studies, finding that they do indeed tend to underestimate actual costs. Yet, it turns out to be difficult to compare the results of different studies, both with each other and with ours because a common denominator is missing. Assumptions, choice of a benchmark and scope often differ between studies, which requires additional effort to make studies comparable. The same limitations apply to the benefit side, which was used to estimate the monetary values of positive externalities associated with agriculture. Yet, some of the external benefits from agriculture, namely those associated with marketable non-agricultural outputs, were directly measured using standard techniques.

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Appendix

Table A.1: Estimated Shadow Costs of Environmental Damages in The Netherlands[a]

Effect on:	Environmental Cost	Data sources[b]	Comments
1. Soil			
Emissions of GHGs	(see below under 3)		
Water management and dewatering of peat soils	Costs for pumping, damming up and dyke maintenance and upgrading are €0.15, €7.25 and €52 per hectare of peat soil	van den Born et al. 2016	Numbers are derived from estimate in Van den Born (2016, Table 4.2) which estimates the costs for pumping, damming up and dykes to be respectively €0.4, €24.8 and €178.1 million.
Soil organic matter and erosion	negligible	Kuhlman et al. 2010	Off-site costs are estimated to be nihil since in the Netherlands the area prone to erosion is very limited. On-site costs are already included in private cost/benefits account of farmers
Soil compaction	€2.70/ha	Kuhlman et al. 2010	Minimum estimate of Kuhlman et al. (2016) is used since costs of CO_2 emissions are considered separately
2. Water			
Nitrogen removal costs	€2.60/kg	Blaij et al. 2013	Study follows the so-called OEI guidelines for social cost-benefit analysis; supplement for nature valuation
Phosphate removal costs	€10.30/kg	Blaij et al. 2013	idem
Compliance costs with pesticide application standards	€2,250 (arable) €2,400 (livestock)	Buurma et al. 2013	
Eutrophication	€ 9.00/kg PO4-3	CE	

(cont.)

3. Atmosphere (air)

GHG emissions (GWP100)	€0.016/kg CO_2	CE	Measured in 2014 euros. Carbon traded at average annual prices of €21.8, €24.4, €14.2, €15.6, €13.4 and €7.4 per tCO_2eq for respective years 2007 through 2012. (NEV, 2015). The 2007-2012 average price is €16/tCO_2.
Acidification	€4.00/kg SO2	CE	
N_20	€15.50/kg	LEI	
Ammonia	€3.14/kg	Walter et al. 2008	

[a] Available from the Netherlands Institute for Biology and Ecology (Nederlands Instituut voor Bouwbiologie en Ecologie, NIBE) at http://www.nibe.info/nl/faq [accessed 17 January 2016].
[b] Data sources refer to various Dutch research organisations: TNO is the organisation of applied science research (Toegepast Natuurwetenschappelijk Onderzoek), CE (Delft) is an independent think tank that studies environmental issues.