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An assessment of the total external costs of UK agriculture

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Abstract

This trans-disciplinary study assesses total external environmental and health costs of modern agriculture in the UK. A wide range of datasets have been analysed to assess cost distribution across sectors. We calculate the annual total external costs of UK agriculture in 1996 to be £2343 m (range for 1990–1996: £1149–3907 m), equivalent to £208/ha of arable and permanent pasture. Significant costs arise from contamination of drinking water with pesticides (£120 m/year), nitrate (£16 m), *Cryptosporidium* (£23 m) and phosphate and soil (£55 m), from damage to wildlife, habitats, hedgerows and drystone walls (£125 m), from emissions of gases (£1113 m), from soil erosion and organic carbon losses (£106 m), from food poisoning (£169 m), and from bovine spongiform encephalopathy (BSE) (£607 m). This study has only estimated those externalities that give rise to financial costs, and so is likely to underestimate the total negative impacts of modern agriculture. These data help to identify policy priorities, particularly over the most efficient way to internalise these external costs into prices. This would imply a redirection of public subsidies towards encouraging those positive externalities under-provided in the market place, combined with a mix of advisory and institutional mechanisms, regulatory and legal measures, and economic instruments to correct negative

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externalities. Further work examining the marginal costs and benefits of UK agriculture would help to inform future policy development.

Keywords: Externalities; Agriculture; Water pollution; Health; Pesticides; Biodiversity; Food poisoning; Policies

1. Definition and concept of externalities

Farmers in the UK have been highly successful at increasing food production in the 20th century. Compared with 1950, per hectare yields of wheat, barley, potatoes and sugar beet have tripled, while milk yields per cow have more than doubled. But these remarkable achievements have also brought costly environmental, health and social problems (Conway and Pretty, 1991; Pretty, 1995, 1998; Mason, 1996; EEA, 1998; Krebs et al., 1999).

Most economic activities affect the environment, either through the use of natural resources as an input or by using the 'clean' environment as a sink for pollution. The costs of using the environment in this way are called externalities, because they are side effects of the economic activity and their costs are not part of the prices paid by producers or consumers. When such externalities are not included in prices, they distort the market by encouraging activities that are costly to society even if the private benefits are substantial (Baumol and Oates, 1988; Pearce and Turner, 1990; Lewis, 1996; EEA, 1998; Brouwer, 1999; Pretty et al., 1999).

An externality is any action that affects the welfare of or opportunities available to an individual or group without direct payment or compensation, and may be positive or negative. The types of externalities encountered in the agricultural sector have five features: (1) their costs are often neglected; (2) they often occur with a time lag; (3) they often damage groups whose interests are not represented; (4) the identity of the producer of the externality is not always known; and (5) they result in sub-optimal economic and policy solutions.

2. Costing negative agricultural externalities

Although several attempts have been made to put a cost on some of the pollution arising from agriculture in the USA and Europe, it has proven difficult to do. First, it is necessary to know about the value of nature's goods and services, and what happens when these are lost. The current system of economic calculations grossly underestimates the current and future value of natural capital (Abramovitz, 1997; Costanza et al., 1997; Daily, 1997).

Second is the difficulty of putting a value on non-market goods. How do we value, for example, skylarks singing on a summer's day, or a landscape with hedgerows and trees, or a watershed producing clean water? Environmental economists have developed methods for assessing people's stated preferences for environmental goods through hypothetical markets (Willis et al., 1993; Hanley et al., 1998;

Brouwer, 1999). The value of nature's goods and services is represented to an extent by people's willingness-to-pay (WTP) for them, and this permits estimation of benefits foregone, the correct economic welfare measure. However, in view of scientific and economic uncertainties about many agriculturally related problems, we use financial costs to help to overcome uncertainties with valuation. This restricts the range of impacts we are able to value, though it can help to overcome the problem of scientific uncertainty where expenditure is incurred in relation to a specific agricultural issue. This approach does not, therefore, actually value the externality, but uses as a proxy the expenditure which society incurs in dealing with that externality (Bailey et al., 1999; Hanley and Oglethorpe, 1999; Hill and Crabtree, 2000).

There have been several studies on the external costs of modern agriculture in Germany, Netherlands, UK and the USA (Pimentel et al., 1992, 1995; Evans, 1995, 1996; Steiner et al., 1995; Davison et al., 1996; Fleischer and Waibel, 1998; Waibel and Fleischer, 1998; Bailey et al., 1999; Ribaudo et al., 1999). These suggest that total external costs are some \$81–117/ha of arable and permanent pasture in Germany (only pesticides and gaseous emissions costed) and the USA, rising to \$112–274 for arable land only (Pretty et al., 2000). For several reasons, however, these data are not wholly comparable in their original form, and methodological concerns have been raised about some studies (Bowles and Webster, 1995; Crosson, 1995; van der Bijl and Bleumink, 1997; Pearce and Tinch, 1998)[1].

The need for estimates of externality costs occurs at two levels. The first is the level at which national and international policy strategies are developed. Here, there is need for estimates of total costs, both overall and by type of externality. These estimates provide a broad guide for policy emphases. Areas in which costs appear to be greatest are then obvious candidates for policy emphases and further analyses.

The second level is that of particular policies, programmes, or projects. Here, estimates of social costs and benefits, in the form of cost-benefit or cost-effectiveness studies, can help guide decisions, for example, about which agri-environmental initiatives are best suited to reducing externalities. Hanley et al. (1999) recently reviewed and summarised a dozen such cost-benefit studies of UK agri-environmental schemes. Such studies are extremely useful in helping to judge whether the costs associated with particular policies or programmes are warranted in terms of their social benefits. However, as Whitby (2000) has recently noted, most evaluations of UK agri-environmental schemes have not actually been able to value benefits at the margin. In other words, even if a scheme has produced more social benefits than costs in a particular area, it is still unknown how reducing or expanding the scheme would affect benefits and costs. Oglethorpe et al. (2000) have recently

[1] Some critiques of earlier studies on externalities have noted that several effects could not be assessed in monetary terms, whilst others have appeared to be more arbitrary (e.g. the cost of bird deaths in the USA (\$2 billion) is arrived at by multiplying 67 million losses by \$30 a bird; Pimentel et al., 1992). The Davison et al. (1996) study on Netherlands agriculture was even more arbitrary, as it added the costs farmers would incur to reach stated policy objectives, and these were based on predicted yield reductions of 10–25% arising from neither cheap nor preferable technologies, which led to a large overestimate of environmental damage (c.f. van der Bijl and Bleumink, 1997).

demonstrated how a true marginal analysis can be used to aid policy development, using the example of a case study in Scotland.

This study is focused on information for policies at the first level, where broad policy strategies are developed. We address the policy implications of this study briefly at the end of the article, and in more depth in a companion article (Pretty et al., 2000). There is need for better information at both levels, however, to guide effectively the future rounds of agricultural policy reform in the UK, throughout Europe, and elsewhere in industrialised countries.

3. Framework for assessing the negative externalities of UK agriculture

In this study, we use a framework of seven cost categories to assess the total environmental and health costs of UK agriculture. Two types of damage cost have been estimated: (1) the treatment or prevention costs (those incurred to clean up the environment and restore human health to comply with legislation or to return these to an undamaged state); and (2) the administration and monitoring costs (those incurred by public authorities and agencies for monitoring environmental, food and health parameters). We have estimated only those externalities which give rise to financial costs.

This framework includes only external costs, i.e. the costs incurred by the rest of society for the actions of farmers. Additional private costs borne by farmers themselves are not included, such as from increased pest or weed resistance from the overuse of pesticides, or for training in the use, storage and disposal of pesticides. However, there remain distributional problems, e.g. insect outbreaks arising from pesticide overuse can affect all farmers, even those not using pesticides.

We have also not yet measured the positive externalities (the beneficial side-effects) created by farming and encouraged by certain policies (OECD, 1997a; Lobley and Potter, 1998; Hanley and Oglethorpe, 1999; van Huyelenbroek and Whitby, 1999; Darling and Topp, 2000). These include: landscape and aesthetic value; recreation and amenity; water accumulation and supply; nutrient recycling and fixation; soil formation; wildlife, including agriculturally beneficial organisms; storm protection and flood control; and carbon sequestration by trees and soils. These are likely to be substantial (Daily, 1997; Smith et al., 1998; Hanley and Oglethorpe, 1999).

Table 1 summarises the annual total external environmental and health costs of UK agriculture. A conservative estimate puts these at £2343 m for 1996 alone (range for 1990–1996: £1149–3907 m). These agricultural externalities can be expressed in a variety of ways:

1. externalities comprise 89% of average net farm income (£2.62 billion), and 13% of average gross farm returns (£17.46 billion) for the 1990s;
2. externalities arising from all 11.28 m ha of arable land and permanent grassland (but not rough grazings) average £208/ha/year;
3. externalities arising from arable farming alone (£1048 m) result in an average cost of £229/ha of arable land (4.58 m ha) — arable farming costs are taken to

Table 1
The annual total external costs of UK agriculture, 1996 (range values for 1990–1996)[a]

Cost category	UK (£ million)	Range[b] (£ million)
1. Damage to natural capital — water		
1a. Pesticides in sources of drinking water	120	84–129
1b. Nitrate in sources of drinking water	16	8–33
1c. Phosphate and soil in sources of drinking water	55	22–90
1d. Zoonoses (esp. *Cryptosporidium*) in sources of drinking water	23	15–30
1e. Eutrophication and pollution incidents (fertilisers, animal wastes, sheep dips)	6	4–7
1f. Monitoring and advice on pesticides and nutrients	11	8–11
2. Damage to natural capital — air		
2a. Emissions of methane	280	248–376
2b. Emissions of ammonia	48	23–72
2c. Emissions of nitrous oxide	738	418–1700
2d. Emissions of carbon dioxide	47	35–85
3. Damage to natural capital — soil		
3a. Off-site damage caused by erosion[c]	14	8–30
3b. Organic matter and carbon dioxide losses from soils	82	59–140
4. Damage to natural capital — biodiversity and landscape		
4a. Biodiversity/wildlife losses (habitats and species)	25	10–35
4b. Hedgerows and drystone walls	99	73–122
4c. Bee colony losses	2	1–2
4d. Agricultural biodiversity	+[d]	+
5. Damage to human health — pesticides		
5a. Acute effects	1	0.4–1.6
5b. Chronic effects	+	+
6. Damage to human health — nitrate	0	0
7. Damage to human health: microorganisms and other disease agents		
7a. Bacterial and viral outbreaks in food	169	100–243
7b. Antibiotic resistance	+	+
7c. BSE[e] and nvCJD	607	33–800
Total	2343	1149–3907

[a] This table does not include private costs borne by farmers themselves.

[b] The ranges for costs do not represent formal standard deviations of the data as this is impossible given the huge variation in types of data and contexts. The ranges represent best estimates for higher and lower quartiles for costs incurred annually during the 1990s. The range values for the external costs in category 2 are calculated from the ranges stated in studies of external costs of each of these gases, rather than the variation of emissions during the 1990s.

[c] The offsite damage caused by erosion in category 3a does not include the costs of removing soils/sediments from drinking water (these are in cost category 1c).

[d] +, Not yet able to calculate costs.

[e] BSE costs are an average for 1996 and 1997.

be 80% of 1a, 2c; 50% of 1b-c, 1e-f, 2a, 2d, 3a-b, 4a-4d, 5a; and 25% of 7a (the total costs arising from livestock systems are higher than for arable largely because of the one-off bovine spongiform encephalopathy [BSE] problem); and
4. pesticide externalities alone average £8.6/kg of active ingredient (a.i.) used in agriculture (22.5 m kg), or £33/ha of land receiving pesticides (on average 3.84 kg a.i./ha) (pesticide externalities are taken to be 100% of 1a, 5; 50% of 1e-f, 4: which equals £193 m).

Modern farming clearly results in substantial external costs per hectare and per kilogram of non-renewable input. These per hectare costs are substantially greater than those estimated in other studies, probably reflecting the more comprehensive nature of the framework and range of impacts measured. Nonetheless, we believe them to be a conservative estimate of the true costs.

4. Why estimates of externalities are likely to be conservative

This study attempts to estimate the total external costs of UK agriculture. Given the multifaceted and dynamic nature of agriculture and its impact on environment and human health, we have had to make many assumptions about the data. In most cases, these result in conservative estimates of costs, though one (the BSE crisis) has inflated the costs above the long-term annual averages, assuming that the expected eradication of BSE does occur.

1. Some costs are known to be substantial underestimates (e.g. acute and chronic pesticide poisoning of humans; monitoring costs; eutrophication of reservoirs; restoration of all hedgerow losses), to be limited to certain geographic areas of the UK (water company returns are for England and Wales only), or currently cannot be calculated (e.g. dredging to maintain navigable water; flood defences; marine eutrophication; poisoning of domestic pets).
2. We do not generally calculate the costs of returning the environment or human health to pristine conditions. Pesticides in drinking water, for example, must not exceed a maximum of 0.5 μg/l for all compounds. Yet BSE represents an example of the cost of complete eradication of a problem. If all cost categories were estimated for such restoration, then the total externalities would be substantially greater than estimated in this study.
3. Treatment and prevention costs may be underestimates of the true costs. This significantly underestimates the true costs of biodiversity loss, since in most cases species and habitat plans aim to restore only a small proportion of previous biodiversity losses. Agriculture's effect on biodiversity is estimated according to the cost of implementing plans to return species and habitats to acceptable levels for society (after accounting for non-agricultural impacts on biodiversity). But this underestimates the non-user values, which may be substantial. We have not estimated people's WTP for option values (the option of

enjoying something in the future); bequest values (ensuring that descendants will be able to derive value); and existence values (the value of knowing that something simply exists). In general, this study accounts for use values, and underestimates the rest (e.g. archaeological remains many have high existence value to some people, yet many have been destroyed by cultivation). In addition, by focusing on costs, this study underestimates how much people might be willing to pay to see positive externalities created (c.f. Willis et al., 1993; Darling and Topp, 2000).

4. This study does not account for time lags between the cause of a problem and its expression as a cost. Some costs incurred in the 1990s may have arisen from activities or technologies long since stopped (e.g. organochlorine residues carried into rivers in Cornwall by eroded soil long after banned from use — RCEP, 1996). Others may not yet be expressed (e.g. accurate predictions about the future number of cases of new variant Creutzveldt-Jakob Disease [nvCJD] are impossible; and the role of pesticides as endocrine disruptors).
5. We have not included the cost of research in this study, as it is impossible to disaggregate research budgets on the basis of allocations for addressing the problems of negative externalities.
6. We do not include the very substantial public subsidy for farming (£3 billion annually during the 1990s), as there is no accepted relationship between provision of subsidies and creation of negative externalities. Subsidies are a transfer from taxpayers to farmers (whether or not external costs are induced). Some of this support is used to create positive benefits, directly through agri-environmental programmes (approximately £100 m annually in the UK to the late 1990s, and rising under CAP reforms), and the removal of public support could, indeed, lead to greater negative externalities, such as via farm amalgamation, removal of hedgerows, and increased pesticide use.
7. This study has sought to estimate only those costs arising from the farm. We have not included the many environmental and social costs associated with getting food from the farm gate to consumers' plates. Transport externalities are likely to be significant (Raven and Lang, 1995; ECMT, 1998). We have also not included an assessment of the costs caused by modern farming on rural communities.

5. Data sources and key assumptions

This study has drawn on 17 datasets collected and maintained by a wide range of agencies and authorities in the UK and rest of Europe:

1. Office of the Director General of Water Services (Ofwat, 1992–1998) dataset of 28 water companies in England and Wales;
2. British Crop Protection Association (formerly the British Agrochemicals Association) data (BAA, 1998);

3. Department of the Environment, Transport and the Regions (DETR, 1998a) data on water pollution;
4. Environment Agency (EA) data on both eutrophication and pollution incidents (EA, 1998a, b);
5. EA data on monitoring of ground and surface water (EA, 1998c);
6. Ministry of Agriculture, Fisheries and Food (MAFF) monitoring data, Pesticides Safety Directorate (PSD), and Veterinary Medicines Directorate (VMD, 1997, 1998; WPPR, 1997);
7. DETR emissions inventory, National Atmospheric Emissions Inventory, and the European Environment Agency (EEA) European Community inventory (DETR, 1998b, c; EEA, 1999);
8. EEA ExternE study for external costs of gases (c.f. Eyre et al., 1997; Holland et al., 1999);
9. DETR National Soils Inventory, and local authority data on accidents and clean-up costs (Evans, 1995; RCEP, 1996; DETR, 1997a; Smith et al., 1998);
10. EEA data on soil erosion and organic matter losses (EEA, 1998);
11. DETR and Institute of Terrestrial Ecology datasets on species losses (DETR, 1997a, b, 1998a, d; EA, 1998c);
12. UK Biodiversity Steering Group (1995, 1998, 1999) by costings for Biodiversity and Habitat Action Plans;
13. DETR data on hedgerow and stonewall losses (DETR, 1997c, 1998d);
14. Rothamsted data on bee colonies and losses since 1940s (Carreck and Williams, 1998);
15. Health and Safety Executive (HSE) data on pesticide poisoning (HSE, 1998a, b);
16. Public Health Laboratory Service (PHLS) data on food poisoning (Wall et al., 1996; Evans et al., 1998; PHLS, 1999); and
17. National Audit Office (NAO) and MAFF data for BSE (NAO, 1998).

5.1. Cost category 1: damage to natural capital — water

Pesticides, nutrients (nitrogen and phosphorus), soil, farm wastes and micro-organisms escape from farms to pollute ground and surface water. Costs are incurred by water delivery companies (and passed onto their customers) to comply with drinking water standards set out in European Union (EU) legislation for pesticides and nitrates (standards for pesticides are 0.1 μg/l for a single product and 0.5 μg/l for total pesticides; for nitrates the maximum is to 45 mg nitrate/l or 10 mg nitrate-N/l), to remove pathogens, particularly *Cryptosporidium*, to pay for restoring water courses following pollution incidents and eutrophication, and to remove soil from water. It is important to note that some costs would be borne whatever type of agricultural system was in use. The key policy question is, are there types of agriculture that could substantially reduce these costs? We also do not assess all external costs, such as the avoidance costs of water consumers switching to bottled water. Companies incur both capital and operating expenditure for water quality treatment. These costs are reported annually by each of the 28 water companies in England

and Wales to Ofwat.[2] We use these, together with various DETR datasets, to estimate external costs at £231 m/year for damage to water. These costs would be much greater if the policy goal were complete removal of all residues/contaminants.

5.1.1. Pesticides in sources of drinking water (1a)

Annual capital expenditure by water companies on pesticide removal between 1992 and 1997 was £124.9 m/year after depreciation (at 1996 prices). Operating expenditure by the 28 companies is generally much higher in the east of England, but is not always reported separately. Based on returns to Ofwat, we estimate annual operating costs for pesticide removal to be £9.5 m. As 89% of pesticides (some 22.5 m kg) are applied in farming (BAA, 1998), the total pesticide costs arising from farming are £119.6 m/year.

5.1.2. Nitrate in sources of drinking water (1b)

Nitrate enters drinking water sources from fertilisers and livestock wastes, from mineralisation of organic nitrogen in the soil, from atmospheric depositions, and from human sewage. Capital expenditure by water companies on nitrate removal between 1992 and 1997 was £18.8 m/year, and operating expenditures £1.7 m (both are higher in the east). We estimate that 80% of nitrogen is from agricultural sources, putting annual external costs at £16.4 m/year.

5.1.3. Phosphate and soil in sources of drinking water (1c)

Phosphate also contaminates water, with some 43% in water estimated to come from agriculture (29% from livestock; 14% from fertilizers), mostly attached to soil particles from eroded land, the remainder coming from point sources (human waste, detergents, industry; RCEP, 1996; EA, 1998a; EEA, 1998; Withers and Jarvis, 1998). Capital expenditure on both phosphate and soil particle removal was £68.8 m between 1992 and 1997, with a further £4.3 m for operating expenditure. Assuming

[2] The government's Office of the Director General of Water Services sets industry price levels each five years, which determine both the maximum levels of water bills and specifies investments in water quality treatment. During the 1990s, water industry undertook pesticide and nitrate removal schemes, resulting in the construction of 120 plants for pesticide removal and 30 for nitrate removal (Ofwat, 1998). Ofwat estimates that water companies will spend a further £600 m between 2000 and 2005 on capital expenditure alone due to continuing deterioration of 'raw water' quality due to all factors. Ofwat predicts capital expenditure for pesticides to fall to £88 m/year at the end of the 1990s/early 2000s; and for nitrate to fall to £8.3 m/year.

Although Ofwat has sought to standardise reporting, individual companies report water treatment costs in different ways. Most do distinguish treatment for pesticides, nitrate, *Cryptosporidium*, and several metals (iron, manganese, lead). The remaining treatment costs for phosphorus, soil removal, arsenic and other metals, appear under a category labelled 'other'. Of the 28 water companies in England and Wales, three report no expenditure on treatment whatsoever; and a further three do not disaggregate treatment costs, with all appearing under 'other'. Twenty companies report expenditure on removal of pesticides, 11 on nitrates, and 10 on *Cryptosporidium*. It is impossible to tell from the records whether a stated zero expenditure is actually zero, or whether this has been placed in the 'other' category. Using Ofwat and water companies' returns, we estimate that 50% of expenditure under the 'other' category refers to removal of agriculturally related materials.

half is for soil removal, and 43% of the remaining phosphorus costs are from agriculture, then total external costs for both phosphorus and soils are £52.3 m.

5.1.4. *Zoonoses in sources of drinking water (particularly* Cryptosporidium*) (1d)*

Water companies must remove some 50 zoonoses derived from livestock, wild animals and human sewage. The most important agricultural contaminant is *Cryptosporidium*, a protozoan causing severe diarrhoeal illness. It is resistant to chlorination and can only be removed by filtration. Expenditure was low in the early 1990s (£27.6 m for 1992–1997), but by the end of the 1990s had risen to £8 m/year (DETR, 1998e). Ofwat, however, has indicated that £66 m/year will be required to meet legal compliances. We take a low–mid range annual figure of £25 m.[3] Until recently, it was assumed that all *Cryptosporidium* arose from animals — low levels of infection are common in cattle, and there are no practicable measures for eradication. But recent research indicates that some strains occur only in humans, and so we assume that 90% of the treatment costs are agricultural externalities, i.e. £22.5 m (Kemp et al., 1995; Sturdee et al., 1998). Type 1 strains of *Cryptosporidium* affect only humans, whilst Type 2 affect both animals and humans, and may be found in both livestock wastes and sewage (ENDS, 1999a, b).

5.1.5. *Eutrophication and pollution incidents from agriculture (1e)*

Farm wastes further disrupt water systems: cattle and pig slurry, silage effluent, dairy wastes that cause eutrophication, and toxic products (such as sheep dips) that kill aquatic life. In each of 1996–1997, there were 31,000–32,000 reports of water pollution in England and Wales from all sources, of which about 20,000 were substantiated (EA, 1998b). Agriculture accounted an average 2600 incidents per year during the 1990s (of which about 50 are in Category 1, 250 in Category 2, 2300 in Category 3). Using the costs incurred by the EA for restocking rivers with fish to restore them to their pre-incident condition, we estimate the total cost of these incidents to be £1.14–2.35 m/year.[4]

[3] Expenditure on *Cryptosporidium* removal is likely to grow: Ofwat assumes that some £1000 m will be invested on improved filtration and for *Cryptosporidium* treatment over 1998–2013 (dwarfing previous requirements for pesticide and nitrate removal); DETR assumes only £120 m, but bases this on only 10 of 28 companies requiring expenditure on *Cryptosporidium* removal.

[4] Pollution incidents are sorted by the EA into three categories. *Category 1* incidents are the most serious and may involve one or more of the following: the closure of a source of water abstraction; an extensive fish kill; a potential or actual persistent effect on water quality or aquatic life; a major effect on the amenity value of the receiving water; or the subsequent need for extensive remedial measures to be taken. *Category 2* incidents are significant but less severe, and may involve the necessity to notify downstream abstractors; result in a significant fish kill; render water unfit for livestock; have a measurable effect on animal life in the water; contaminate the bed of the river or canal; or reduce the amenity value of the water to their owners or to the general public. *Category 3* incidents are relatively minor and have no significant or lasting effect on the receiving water. The EA buys fish at a cost of £500–1000 for 1000 1-year old fish, and £900–1900 for 1000 2-year olds. We estimate the 50 Category 1 incidents kill 4000–5000 fish per incident; the 250 Category 2 incidents each to kill 25–50% of this total; and the 2300 Category 3 incidents to kill 5–10%. These costs, however, include only the restocking of the fish that were lost and do not account for the losses of invertebrates and other aquatic life. The cost of river aeration and labour are also not included.

Eutrophication affects water supply (algae can block filters, stimulate bacterial growth, and give drinking water an unpleasant taste), irrigation, fisheries, navigation, water sports and angling (Mason, 1996; EA, 1998a; Withers and Jarvis, 1998). Between 1989 and 1997, some 3000 freshwater bodies have been affected by algal blooms, some of which have caused human health problems, the deaths of sheep and dogs, and the closure of water bodies for recreation. Most reservoirs in eastern England suffer periodically from an inability to treat water owing to a high concentration of plankton, leading to costly closure of treatment works for periods of up to 2–6 months (EA). There are no national data on the costs of eutrophication, though the remedial costs in reservoirs alone have been estimated to be £4 m/year (RCEP, 1996). Marine eutrophication, comprising algal blooms, red tides and anoxia in deep waters, is also increasingly common, but costs are not estimated in this study.

5.1.6. Monitoring and advice on pesticides and nutrients (1f)

Costs are incurred by the PSD, VMD, and the EA for monitoring of pesticide residues and nutrients in food and the environment, and for administration of schemes and grants to reduce pollution and for advisory services. The costs are £5.4 m for pesticide monitoring in food and livestock, and £4.75 m for monitoring pesticides at 2500 surface and groundwater sites.[5] No data are available on residue monitoring carried out by supermarkets and food processors. The UK government also incur £0.55 m costs in providing advice to farmers to encourage the adoption of more sustainable nutrient and catchment management. Although we include these costs in the analysis, it could be argued that an alternative, more sustainable agriculture, would still incur such monitoring costs.

5.2. Cost category 2: damage to natural capital — air

Agriculture contributes to atmospheric pollution through the emissions of four gases: methane from livestock, nitrous oxide from fertilisers, ammonia from livestock wastes and some fertilisers, and carbon dioxide from energy/fossil fuel consumption and loss of soil carbon. According to the National Atmospheric Emissions Inventory and the EEA inventory (DETR, 1999b, c; EEA, 1999), UK agriculture annually emits 1.064 m tonnes of methane, 0.098 m tonnes of N_2O, 0.278 m tonnes of ammonia, and 0.75 m tonnes of CO_2-C (these data do not include a factor for soil carbon loss). These in turn contribute to atmospheric warming (CH_4, N_2O and

[5] The PSD pesticide residues monitoring programme took 3000 samples in 1997 (down from 4000 in 1996) from retail outlets, which were subjected to 80,000 analyses, at a cost of £1.7 m (£2 m in 1996; WPPR, 1997). The VMD tested 39,152 samples of domestic and imported livestock foodstuffs for residues through a statutory programme to implement EU legislation, with annual costs of £2.7 m, and in a non-statutory programme funded by MAFF conducted 16,767 analyses on 2547 samples at a cost of £1 m (VMD, 1997, 1998; MAFF, 1998). The EA subjects water to 200,000 pesticide analyses; at 8% of sites, Environmental Quality Standards were exceeded by at least one pesticide (EA, 1998c). The cost is not recorded by the EA, but assuming similar unit costs as for the PSD, we put the annual cost at £4.75 m.

CO_2), ozone loss in the stratosphere (N_2O), acidification of soils and water (NH_3) and eutrophication (NH_3; DETR, 1998b, c; EEA, 1999).

Extensive research is underway on the external costs of these gases (Pearce et al., 1996; Eyre et al., 1997; Holland et al., 1999). The ExternE study on the external effects of climate change gases includes analysis of impacts on climate change, health, parasitic and vector borne diseases, sea-level rise, water availability, biodiversity, and storm, flood and drought incidence (Eyre et al.). It puts the marginal costs of methane at £263/tonne (range £239–353); of nitrous oxide at £7530/tonne (range £4267–17,333); and of carbon dioxide (as C) at £63/tonne (range £47–113).[6] The external costs of ammonia have been calculated by identification of emissions, changes in exposure/impacts, quantification of impacts, and valuation based on WTP, using the more conservative VOLY (value of a life year) concept, rather than the VOSL (value of a statistical life), and indicating an external cost of £171/tonne (range £83–259) (Holland et al.). These studies indicate that annual external costs of these gases arising from UK agriculture are £280 m for CH_4, £738 m for N_2O, £47 m for CO_2, and £48 m for NH_3.

5.3. Cost category 3: damage to natural capital — soil

5.3.1. Off-site damage caused by soil erosion (3a)

A healthy soil is vital for agriculture, but modern farming has accelerated erosion, primarily through the cultivation of winter cereals, the conversion of pasture to arable, the removal of field boundaries and hedgerows, and overgrazing of animals on grasslands (Evans, 1995, 1996; RCEP, 1996; DETR, 1997a; EEA, 1998). Soil erosion causes both on- and off-farm problems.[7] We do not include internal costs, even though loss of soil fertility represents a loss of public good in the long-run. Off-site costs arise when soil carried off farms by water or wind blocks ditches and roads, damages property, induces traffic accidents, increases the risk of floods, and pollutes water through sediments and associated nitrate, phosphate and pesticides. Evans, using data from local authorities, estimates that the national external costs to property and roads alone to be £13.77 m (£4 m for damage to roads and property; £0.1 m for traffic accidents; £1.19 m for footpath loss; £8.47 for channel degradation), but not counting water company costs (see category 1) or losses to fisheries.

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[6] The data in the Open Framework and FUND models take account of differences in discount rate, are weighted according to wealth differences in affected countries, and take account of 'social contingency' (the capacity of regions/countries to adapt to change). This means that uncertainty is still very large (c.f. Eyre et al., 1997). We adopt a conservative figure for damage costs based on a quarter of the difference between the lowest and highest estimates contained in the Open and FUND models, and according to two different discount rates (1 and 3%).

[7] Costs incurred by farmers themselves from soil erosion arise from: (1) loss of organic matter leading to decreased water holding capacity of soils and increased run-off; (2) loss of organic matter-rich soils reduces yields as crops are slower to germinate; and (3) loss of nutrients and crops themselves in water and wind erosion. Evans (1995, 1996) estimates the annual on-farm costs of soil erosion to be £10–11 m (1996 prices).

5.3.2. Organic matter (OM) and carbon dioxide losses (3b)

Soils in England, Wales and Scotland contain some 21.78 billion tonnes of carbon (Howard et al., 1995; DETR, 1997a; Smith et al., 1998). Arable soils contain on average 162 tonnes C/ha, permanent pasture 207 tonnes C/ha, and soils under semi-natural vegetation 350 tonnes C/ha. Most carbon in the UK is in Scottish peats (16.4 billion tonnes alone). Carbon accumulates in soil when arable land is converted to grassland or forest, and when sustainable farm practices lead to OM incorporation, but it is rapidly lost when pastures are ploughed or when agricultural land is intensively cultivated (Kätterer and Andrén, 1999). The OM content in UK soils has declined in recent years (DETR; EEA, 1998; but see Skinner and Todd, 1998, for another view). Soils lose CO_2 when OM is lost, and using estimates of soil OM loss, we calculate that 20% of arable soils (0.92 m ha) have lost 1.7% or more of OM since 1980, amounting to 1.42 tonnes C/ha/year.[8] Given an external cost for CO_2 of £63/tonne (range £47–113), this puts the annual cost at £82.3 m (range £59–140).[9]

5.4. Cost category 4: damage to natural capital — biodiversity and landscape

5.4.1. Biodiversity and wildlife (habitats and species) (4a)

Modern farming has had a severe impact on wildlife: 170 native species have become extinct this century, including 7% of dragonflies, 5% of butterflies and 2% of fish and mammals. In addition, 95% of wildflower-rich meadows have been lost since 1945; 30–50% of ancient lowland woods; 50% of heathland; 50% of lowland fens, valley and basin mires; and 40% of hedgerows (DETR, 1998d; Pretty, 1998). Species diversity is also declining in the farmed habitat itself. Draining and fertilizers have replaced floristically rich meadows with grass monocultures, overgrazing of uplands has reduced species diversity, and herbicides have cut diversity in arable fields. Farmland birds have particularly suffered: the populations of nine species fell by more than a half between 1970 and 1995 (Campbell and Cooke, 1997; Pain and Pienkowski, 1997; Mason, 1998).

In this study, we use the costs of restoring species and habitats under the Biodiversity Action Plans (BAPs) as a proxy of the costs of wildlife and habitat losses. These plans contain costed targets and action plans for 406 priority species and 38

[8] According to the National Soils Inventory (DETR, 1997a), there was an increase between 1980 and 1995 in the proportion of arable topsoils found to have OM concentrations of $<3.6\%$ (from 32 to 41% of samples) and a corresponding decrease in the number of topsoils with $>7\%$ OM (from 22 to 11%)[8]. Thus with 11% of samples showing OM declines from 7 to 5.3% (mid-range) and a further 11% showing OM decline from 5.3 to $<3\%$, this gives a value of 20% of soils (assuming these losses occur mainly in arable soils, and that rough and permanent pastures are largely carbon neutral, this suggests losses on 0.92 m ha) showing OM declines of 1.7% or more since 1980. We therefore assume a loss of soil OM of 1.7% in a 20 cm depth; given a typical dry bulk density of 1.25 g/cm^3 (range 1.1–1.6); and given that approximately 50% of soil OM is carbon (20–75% range), this suggests losses of 21.3 tonnes C/ha over 15 years, or 1.42 tonnes C/ha/year.

[9] Under deliberate management for soil OM and carbon accumulation, such as zero tillage and cover cropping, it is possible for soils to accumulate some 22.8 tonnes C/ha/year — a benefit of £1596/ha/year (Smith et al., 1998).

key habitats (UK Biodiversity Steering Group, 1995, 1998, 1999; DETR, 1997a, b).[10] For those species and habitats for which agriculture is identified as one of the factors causing problems, we have used details in each of the BAPs to estimate that half of the costs of actions to protect and restore them can be attributed to agriculture. These plans aim to restore only a proportion of past species and habitat declines, so they underestimate the cost of biodiversity loss.

The total costs of plans for species affected by farming practices and partly dependent on farmland is £1.69 m/year (10 vertebrate species £1.25 m; 16 invertebrates £0.27 m; and 20 plant species £0.22 m). The average annual cost of a habitat plan is £2.37 m, which puts the total cost for farmland habitats and habitats affected by farming practices to be £22.39 m/year. This gives an annual total for both species and habitats affected by agriculture of £24.6 m.

5.5. Hedgerows and drystone walls (4b)

Hedgerows and stonewalls are important for landscape, wildlife and cultural value, as well as being valuable for soil conservation and stock control, and as habitats for beneficial insects and birds. We use the amount that farmers receive for replacing hedgerows and drystone walls under agri-environment schemes as a proxy for cost. Net hedgerow stock declined from 563,000 to 377,500 km between 1984 and 1993, an average loss of 18,560 km (DETR, 1997c, 1998d). But taking into account hedgerow restoration (5700 km/year), the total annual losses are some 24,260 km (only 15% is due to outright removal, the remainder becoming derelict due to poor management). Farmers receive £2–4/m to restore hedgerows, putting the cost to restore just one year's total loss of 24,260 km to be £72.8 m (range of £48.5–97.0 m).

Over the past 40 years, 7000 km of drystone walls have been lost from upland landscapes; 50% of the remaining 112,000 km have become derelict and no longer stockproof, and a further 46% are in need of some restoration. Assuming a cost of £16/m for lost stonewalls, £12/m for derelict walls, and £4/m for restoration (restoration grants of £12–16/m are available under the Countryside Stewardship Scheme), then the annual cost is £24.8 m.

5.5.1. Bee colony losses (4c)

Honey and bumble bees are the most important insect pollinators in the UK, pollinating some 70 crops. There are 200,000 honey bee colonies in the UK, owned

[10] The BAPs contain some farmland species (e.g. skylark) and habitats (e.g. cereal field margins), for which the costs relate primarily to agriculture. Other species (e.g. song thrush) and habitats (e.g. saltmarsh) are partly dependent on farming, or have declined partly as a result of agricultural practices (e.g. great crested newt, fens; UK Biodiversity Group, 1995, 1998, 1999). The cost per habitat has been calculated by taking the mean of 1997 and 2000 costings. The habitat plans cover only public expenditure; are additional to existing financial commitments; include the costs of managing public sector land, and the costs of land management scheme payments (including administration); take account of revenue from land management (e.g. reeds and grazing); include land purchase costs, both the costs of public sector acquisition and grants for private sector purchase; and exclude the costs of research, monitoring, advice to managers, site safeguard and designations and publicity. For this study, only habitat management, restoration and creation costs are included.

by 35,000 beekeepers (of whom only 300 are commercial). Carreck and Williams (1998) put the total annual value of bees at £153.6 m (90% for pollination; 10% for honey and beeswax) — roughly £770/colony (1996 prices). Although bees are damaged by modern agriculture through exposure to pesticides and the loss of habitat (e.g. loss of flower-rich meadows), there are no estimates of the costs of bee losses[11]. However, a 1943 study indicated that there were 429,000 colonies (Butler, 1943), suggesting a loss over 53 years of some 4320 colonies per year. It is impossible to say how much of this decline is directly due to modern agriculture (the parasitic mite, *Varroa jacobsoni*, has killed many colonies, and demand for domestic honey has changed). But as bee keepers are unable to meet the demand for pollination services (indicating a shortage of bees), we assume that half of the losses are due to modern agriculture — some 2160 colonies/year, putting the cost at some £1.73 m.

5.5.2. Agricultural biodiversity (4d)

In addition to the loss of wild biodiversity, agricultural biodiversity has been declining sharply during the course of this century (Fowler and Mooney, 1990; Heywood, 1995; RAFI, 1997). It is currently not possible to put a cost on these losses of genetic diversity, particularly where whole species or varieties are concerned.

5.6. Cost category 5: damage to human health — pesticides

Pesticides can affect workers engaged in their manufacture, transport and disposal; operators who apply them in the field; and the general public. Estimates for the external health costs of pesticides are almost certainly considerable underestimates, owing to differing risks per product, poor understanding of chronic effects (e.g. in cancer causation), weak monitoring systems, and misdiagnoses by doctors (Repetto and Baliga, 1996; HSE, 1998a, b; Pearce and Tinch, 1998; Pretty, 1998):

5.6.1. Pesticides — acute effects (5a)

It is very difficult to say exactly how many people are affected by pesticides each year. According to voluntary reporting to the HSE, some 100–200 incidents occur each year, of which few are substantiated.[12] However, recent HSE research indicates significant under-reporting (HSE, 1998a, b). One survey of 2000 pesticide users found that 5% reported at least one symptom in the past year and about which they

[11] The National Bee Unit confirmed only 82 colonies affected in 1998 out of 200,000. In the USA, the number of honey bee colonies has declined from 5.9 million in 1987 to 2.8 million in 1994. Each year, some 15,000 colonies are affected by pesticides (Hoff and Willett, 1995; Nabhan and Buchmann, 1997).

[12] Fatalities from pesticides at work in Europe and North America are rare — one a decade in the UK, and eight a decade in California. In the UK, a variety of institutions collect mortality and morbidity data, but in California, where there is the most comprehensive system of reporting in the world, official records show that some 1200–2000 farmers, farmworkers and the general public are poisoned each year (CDFA, 1972–current *passim*; Pretty, 1998). There appears to be greater risk from pesticides in the home and garden where children are most likely to suffer. In Britain, 600–1000 people need hospital treatment each year from home poisoning.

had consulted a doctor. A further 10% had been affected (mostly by headaches), but had not consulted a doctor. As some 105,000 farmers hold pesticide certificates in Britain, this suggests that at least 5250 farmers suffer sufficient symptoms to consult a General Practitioner (GP) each year, and a further 10,500 are adversely affected to a lesser degree. This suggests the annual costs borne by farmers and the health system are £1.05 m.[13] Strictly, though, these are mostly private costs borne by farmers (except for GP consultations and effects on hired workers).[14]

5.6.2. Pesticides — chronic effects (5b)

Chronic health hazards associated with pesticides are even more difficult to assess. The most controversial issue is whether or not some products are carcinogenic. Pesticides are ingested via food and water, and these represent some risk to the public. With current scientific knowledge, it is impossible to state categorically whether or not certain pesticides play a role in cancer causation. In this study, therefore, we do not include the external costs associated with chronic health effects.

5.7. Cost category 6: damage to human health — nitrate

Nitrate is not toxic to humans, though it can be reduced by bacteria in the gut or mouth to nitrite, which is a well-established cause of methaemoglobinaemia (blue baby syndrome), which lessens the capacity of the blood to carry oxygen. Acquired methaemoglobinaemia is most likely to occur in infants in the first few months of life, though there have been no cases since the 1950s in Britain. The link between nitrate and cancers of the stomach, bladder and oesophagus through the formation of nitrosamines was long suspected to be a health risk, but epidemiological and other studies have not yet proven causation. For this study, we assume that nitrate causes no direct external health costs in the UK (nitrate does have to be removed from drinking water to meet legal standards — see cost category 1b).

5.8. Cost category 7: damage to human health — micro-organisms and other disease agents

5.8.1. Bacterial and viral outbreaks in food (7a)

In the UK, the main food poisoning threats arise from *Bacillus*, *Campylobacter*, *Cryptosporidium*, *Clostridium*, *Escherichia coli*, *Listeria*, *Salmonella* and Small Round Structured Virus. According to the PHLS, food poisoning incidents have

[13] Assuming the value of a symptom-day for farmers and farmworkers is £75, and that 5250 farmers are off work for one day, the 10,500 for half a day, and GP consultations cost some £50 each (assuming each ill person does go to a GP, and that the cost of illnes is a good measure of WTP).

[14] The use of organophosphates (OPs) by sheep farmers represents a special case. OPs react with acetyl cholinesterase, an enzyme playing a key role in terminating the transmission of nerve impulses. As OPs inhibit this enzyme, they can cause continuous nerve stimulation, leading to headaches, giddiness, nausea, blurred vision and rapid heart action. Once again, though, it is farmers and farmworkers who are affected. It is now thought that 6000 out of 90,000 sheep farmers are suffering ill-health from exposure to sheep dip chemicals (MAFF, 1998), putting the private cost of this poisoning at £3.47 m/year.

risen sharply in recent years to 94,000/year in 1997 (average of 9000 in the 1950s; 6000 in the 1960s; 8000 in the 1970s; 17,165 in the 1980s; and 72,078 in the 1990s; Wall et al., 1996; Evans et al., 1998; PHLS, 1999). However, it is also known that notified cases represent only about 3% of total morbidity (one in 30 cases notified) — people may suffer mild infection, become ill but not seek medical attention, or be seen by a doctor who fails to notify (Wall et al.).

We use reported PHLS data for 1992–1996 on modes of transmission to allocate costs for food poisoning (Cowden et al., 1995; Djuretic et al., 1996; Evans et al., 1998). We assume that the 88,000 notified cases (average for 1996–1997) represent the tip of 2.64 m cases (at a 30:1 ratio), with 3% notified, 22% consulting a GP, 30% ill but not seeking medical attention, and 45% with mild symptoms (Wall et al., 1996). The total costs of all food poisoning (lost wages, consultations with doctors, hospital beds) are estimated to be £677 m/year.[15] We conservatively assume that only 25% of these cases of food poisoning arise directly from UK farming — some arise from food processing, from domestic and commercial preparation (such as from infected food handlers), from consumption of contaminated imported foods, and from non-farmed foods such as shellfish. This puts the annual costs at £169 m (range £100–243 m).

5.8.2. Antibiotic resistance (7b)

Some 1225 tonnes of antibiotics are used in the UK each year — 40% for humans; 30% for farm animals; and 30% for domestic pets and horses. Antibiotics and other antimicrobials are used in modern agriculture for: (1) therapeutic treatment of clinical diseases (20%); and (2) prophylactic use and growth promotion (80% of total), though they are not used in certified organic farming. Concern is growing that overuse of antibiotics may render some human drugs ineffective and/or make some strains of bacteria untreatable. The World Health Organisation has documented direct evidence that antimicrobial use in farm livestock has resulted in the emergence of resistant *Salmonella*, *Campylobacter*, *Enterococci*, and *E. coli* types (WHO, 1997). Some 20–50% of antibiotics used by humans and 40–80% of those used in farming are thought to be unnecessary (Harrison and Lederberg, 1998; Wise et al., 1998).

Evidence shows that some emerging resistance problems, such as vancomycin-resistant *Enterococci*, are linked to the overuse of antibiotics both in hospitals and on farms (House of Lords Select Committee on Science and Technology, 1998).[16] However, it is currently impossible to estimate the external costs of antibiotic overuse.

[15] We estimate the costs in the following way: 88,000 notified cases with 1 week off work (at £375 and cost of lost business of £200), of which half are hospitalised see consultants, plus the costs of laboratory tests on samples, giving £158.4 m. The 580,000 cases that see a GP are off work for 3 days (£225 plus £120), plus GP consultation costs (£50), giving a total of £200 m. The 792,000 cases that are ill but seek no medical advice are off work for 2 days (£150 plus £80), giving a total of £182 m. And the 1.19 million with mild symptoms miss 1 day (at £75 plus £40), giving a cost of £137 m. The total is £677 m/year.

[16] Vancomycin-resistance is now suspected of being linked to farm use of avoparcin, which was banned by the EU in 1997. According to the PHLS, one strain of *Salmonella*, *S. typhimurium* DT104, is resistant to at least four antibiotics: it first appeared in the UK in 1990 and now accounts for 15% of all *Salmonella*

If antibiotic use in farms was to lead to the loss of efficacy of a single human drug per year, then the cost of its replacement would be substantial. The cost would be very much higher if overuse of antibiotics meant a complete return to a pre-antibiotic era.

5.8.3. BSE and nvCJD (7c)

When BSE was first identified in late 1986, research confirmed that it was a member of a group of transmissible diseases occurring in animals and humans. It appeared simultaneously in several places in the UK, and has since occurred in native-born cattle in other countries. By May 1998, 171,598 cases had been confirmed in the UK, the epidemic having reached a peak in 1992 (37,000 cases in 1992, falling to 2040 in 1998; NAO, 1998). The link between BSE and nvCJD in humans was confirmed in 1996, and 35 deaths from nvCJD were recorded between 1996 and early 1999. There are still major uncertainties over the possible spread of CJD. Some still contest whether BSE is indeed a causative factor in CJD. It is also not known: (1) how much BSE-contaminated beef entered the food system and was consumed; (2) the incubation period in humans; (3) the extent of the species barrier between humans and animals; and (4) how the genetic code of individuals makes them more or less likely to contract the disease. The external costs of BSE have been substantial, averaging some £607 m for each of 1996 and 1997 (some 49% of the total costs caused by BSE[17]; Table 2).

6. Implications for policy

This study has shown that the total external costs of agriculture in the UK are substantial, comprising £2343 m, or 89% of average net farm income for 1996. This aggregate is equivalent to £208/ha/year averaged across all 11.28 m ha of arable land and permanent grassland (but not rough grazings). Pesticide externalities are £8.60/kg of a.i. used in agriculture, and £33/ha of land receiving pesticides. The problems associated with valuing non-market impacts mean that our estimates are conservative. The costs incurred in correcting externalities are only a proportion of the total externalities themselves. In this assessment, some costs also appear low, such as the effects of pesticides on human health, as their complex behaviour is poorly understood and so not yet costed.

food poisoning cases. Other pathogenic bacteria becoming more resistant to antibiotics include *E. coli* 0157, responsible for the deaths of 20 people in Scotland in 1997. The UK House of Lords Select Committee on Science and Technology (1998) reported on antibiotic resistance, and concluded that the use of antibiotics in feed for growth promotion should be banned.

[17] It could be argued that compensation payments are also a measure of the external costs of BSE — they are a cost to the taxpayer as a result of problems caused by farming. As they aim to cover income losses as a result of BSE, they could arguably be used as a measure of the net costs BSE has imposed on society (not just a transfer payment). They are an external cost in as much as society as a whole is required to bear the burden of the costs which the BSE crisis has caused to the farming industry (they have become externalised through public policy). However, for this study, we still leave this outside the framework.

Table 2
The costs of BSE in the UK[a]

Cost category	Average cost for each of 1996 and 1997 (£ million)
Compensation payments to farmers	
New schemes — market support measures, selective cull, cattle traceability, beef assurance, over 30 months scheme (OTMS), certified herd scheme	547
Extensions of old schemes — Beef Special and Suckler Herd top-ups, Hill Livestock Compensatory Allowances	94
Subtotal	641
External costs	
Payments to abattoirs and renderers for storage, transport, disposal and incineration under OTMS, Calf Processing Aid Scheme, and emergency aid to slaughter, rendering and hide industry	346
Additional purchases into intervention due to BSE crisis	175
Administration and staffing[b]	79
CJD in humans[c]	7
Subtotal	607

[a] Source: NAO (1998).
[b] An extra 930 staff were employed by Intervention Board and MAFF in 1996–1997.
[c] CJD deaths — assuming 11 deaths per year at a VOSL of $1 million.

This study raises several important policy questions. First, how best can efficient policies be developed to lessen these externalities? Second, which farmed hectares contribute the most to externalities, and how can policy efficiently target these over farms that are not significant sources of externalities? Third, what are the aggregate positive externalities provided by agriculture — given that these may exceed negative externalities in some farm systems? As yet, the data is too aggregated precisely to answer these questions. And fourth, what are the best approaches to ensure that harmed parties are adequately compensated?

As this paper has focused on the total external costs of UK agriculture, it indicates the broad policy priorities for reducing total externalities. It highlights the need for policy reform, and the relative scale of the various external costs associated with modern agricultural practice. Further analysis of the marginal external costs of agriculture presents significant methodological challenges, but would help to inform more detailed policy development.

In the meantime, a more fair and efficient use of these public resources would be achieved if policy sought more explicitly to internalise these external costs. This would imply a redirection of public aid from polluting activities to sustainable practices, with subsidies used to encourage those positive externalities under-provided in the market place, combined with a mix of advisory and institutional mechanisms, regulatory and legal measures, and economic instruments to correct negative externalities. In practice, effective pollution control and explicit supply of desired public goods requires a mix of all three approaches, and considerable integration across sectors (c.f. Lewis, 1996; OECD, 1997b; Rayment et al., 1998; Ribaudo et al., 1999; Pretty et al., 2000). The result would be more efficient policy solutions and a significant contribution to the sustained viability of UK farming.

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