The Contribution of Agriculture to Green Growth

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Executive Summary

Green growth is the pursuit of economic growth and development, while preventing environmental degradation, biodiversity loss and unsustainable natural resource use. The aim is to maximise the chances of exploiting cleaner sources of growth, thereby leading to a more environmentally sustainable growth model.

Agriculture faces considerable challenges in implementing a green growth strategy. Anticipated growth in the demand for food and agricultural raw materials due to expanding world population and incomes will place considerable demands upon scarce natural resources, particularly land and water, used in the sector. Although agriculture is not expected to add significantly to job creation in the OECD countries due to the relatively small contribution that the sector makes to total employment, its use of purchased inputs and the supply of food and raw materials to other sectors are significant for employment and total economic activity. Agriculture will continue to be a significant source of employment and income in many non-OECD countries and will play an important part in their future economic development.

Productivity growth in agriculture has played a major role in economic growth in OECD countries. The rate of growth in total factor productivity in agriculture has exceeded that in many other sectors. Labour freed from agricultural activities has fuelled economic expansion and employment growth in those sectors. Crop yields and the productivity of animals have risen substantially and the real price of food has declined. The share of consumers' expenditure devoted to food has fallen and this has increased disposable income available for purchases of other goods and services. If productivity growth in global agriculture is not sustained in the face of increasing global demand, real prices and share of expenditure devoted to food are likely to increase, thereby affecting growth and employment creation in the rest of the global economy.

In comparison to many other sectors, agriculture is unusual in that it can generate both negative and positive environmental externalities and can contribute to the supply of public goods. The anticipated large expansion in the demand for its products could lead to an increase in the negative contribution of agriculture to global environmental quality, for example, loss of biodiversity through the clearing of grassland and forests, unsustainable pressure on increasingly scarce water supplies or increased water pollution by agro-chemicals and animal waste. Data for the OECD countries suggest some modest improvements have been made in reducing the environmental damage associated with agricultural activities since the early 1990s and there has been increased emphasis on strengthening the positive environmental contribution of the sector.

Agriculture will be affected by global climate change. Although higher temperatures and increased concentration of carbon dioxide in the atmosphere could increase average yields for some crops, the likelihood that extreme climatic events will become more common raises the possibility of greater variability in global food production and prices. Producers, consumers and policymakers will face challenges in dealing with increased variability.

Policies introduced to address the emission of greenhouse gases (GHG) could have both an indirect and a direct effect on future agricultural growth. Agriculture has become increasingly dependent on purchased inputs, such as fertilizer and agro-chemicals, whose prices could be affected by economy-wide measures designed to reduce carbon emissions. In addition, specific measures might be used to address GHG emissions generated by crop and livestock production. Policy measures that are designed to reduce

the contamination of water supplies or to achieve other environmental objectives, such as the protection of biodiversity, could also have an effect on agricultural activities and the cost of food. In contrast, there are opportunities for the sector to contribute to the mitigation of climate change through carbon sequestration and the potential for reducing the overall environmental footprint of the sector through the development and adoption of production methods that place less environmental stress on land, water, and wildlife habitat.

The food sector as a whole is a significant consumer of energy. Much of the growth in energy use has been driven by changes in lifestyle and consumer preferences, particularly the demand for more processed and ready-to-eat foods. There is a substantial amount of product wastage throughout the system. Greater efficiency in the use of energy is possible and also increased use of waste products. Overall, if the food and agricultural system is to adapt to the requirements of green growth there will be a need for technological innovation, improvements in human capital, and an appropriate policy environment to facilitate the transition to new production systems.

A wide array of policies, affecting agriculture and the food system directly and indirectly, has implications for green growth. Policies that contribute to the intensification of production in the absence of any offsetting measures to protect environmental quality have a negative environmental impact. Price and income supports that are linked to current production are problematic in this regard, as well as explicit or implicit subsidies which stimulate the use of potentially damaging chemical inputs and energy or the overuse of water. Policies designed to increase the use of agricultural crops for the production of biofuels also raise issues with respect to the intensification of production, in addition to promoting changes in land use in some countries with consequential implications for biodiversity.

Policies that are designed to improve environmental performance in the sector are likely to involve a mixture of market-based and regulatory approaches. Policy options need to be assessed from the perspectives of effectiveness and efficiency, as well as their distributional implications. In addition to the removal of existing policy measures that contribute to a reduction in environmental quality, greater targeting of incentives that are designed to improve environmental outcomes in the sector is needed, both to increase their efficiency and to economise on scarce public funds. Adoption of environmentally-friendly technologies and improved management of resources have important roles to play in achieving green growth in agriculture. Both the public and private sectors need to be active in these areas and in helping to facilitate innovation that will contribute to the greening of agriculture and the food system.

While many of the policy needs for achieving green growth in agriculture are domestic in nature, there are important international dimensions. Multilateral efforts to eliminate non-green policies could help to improve the environmental performance of the sector. International trade will continue to play an important role in the food and agricultural system, both from the perspective of meeting future food needs and through helping to buffer the system against the effects of fluctuations of supply through extreme climatic events. Maintaining open markets and broadening international cooperation will be important in achieving green growth in the agricultural sector.

1. Introduction

In 2009 OECD Ministers adopted a declaration on green growth (OECD, 2009a). In the declaration they observed that "economic recovery and environmentally and socially sustainable economic growth are the key challenges that all countries are facing today" (p. 1). In an OECD report on green growth to the Ministerial Council in 2010 it was observed that "Green growth can be seen as a way to pursue economic growth and development, while preventing environmental degradation, biodiversity loss and unsustainable natural resource use. It aims at maximising the chances of exploiting cleaner sources of growth, thereby leading to a more environmentally sustainable growth model." (OECD, 2010a, p. 13). The strategy for green growth proposed by OECD Ministers includes encouraging green investment and the sustainable management of natural resources by using efficient and effective policies to change behaviour and to foster appropriate private sector responses. Ministers also committed to encouraging domestic policy reform to remove existing policies that have negative environmental outcomes (OECD, 2009a).

This paper examines key issues in implementing green growth objectives in agriculture. The primary focus is on the agricultural sectors of OECD countries, although some implications for non-member countries are also highlighted. Green growth policies will not only have an impact at the farm level, but will affect the food and agricultural system more generally. The implications of policies for up-stream and down-stream industries beyond the farm-gate are also noted.

Agriculture has a number of economic, social and environmental roles. The primary focus in this paper is on economic and environmental dimensions in the context of a green growth strategy.

2. The contribution of agriculture to economic growth and environmental quality

Agriculture plays a major role in economic growth and development. As the provider of food it is a cornerstone of human existence. As a furnisher of industrial raw materials it is an important contributor to economic activity in other sectors of the economy. Agriculture is a substantial user of natural resources, particularly land and water. Its activities have a major impact on the availability of these resources and their quality. As an industry founded on biology, agriculture has a major impact on ecosystems and on non-agricultural plants and animals, particularly in terms of biodiversity. As with most forms of human activity, agricultural activities can have negative environmental impacts (generate negative environmental externalities) manifested in soil degradation and erosion, air and water pollution, and loss of biodiversity. However, in contrast to many other forms of economic activity, agriculture can also generate positive externalities as reflected in the creation and maintenance of attractive landscapes, and contributing to the management of water supplies and maintenance of wildlife habitat.

2.1. Agriculture's role in economic growth

Agriculture has played, and continues to play a key role in global economic development. Pre-industrial economies were characterised by a large share of the economically active population engaged in an agricultural sector characterised by low labour productivity. The presence of surplus labour in agriculture was identified by Lewis (1955) as a pre-condition for growth in the rest of the economy. Lewis argued that the agricultural sector provides a source of labour (and capital) that can be redirected into other areas of the economy to fuel the expansion of output in those sectors. The exit of labour from US agriculture to more productive non-agricultural uses in the period after the Second World War has, for example, been identified as a major contributor to the high rate of economic growth experienced in the United States until the early 1970s (Denison, 1985). The key role played by increased agricultural productivity in economic growth in Japan (Ōkawa and Rosovky, 1960 and 1973) and in Europe (Johnson, 1997) has also been documented.

However, as labour is withdrawn from agriculture output will fall unless the resources that remain can be used more efficiently such that overall productivity increases. Over the longer term, labour-saving technologies need to be generated and adopted by farmers so that the productivity of the labour that remains in agriculture can be increased substantially. As has been noted by a range of authors, high productivity growth in agriculture has been an essential factor in achieving broader economic development in many countries (*e.g.*, Johnston and Mellor, 1961; Rostow, 1959). Johnson (1991) estimates that the average growth rate in labour productivity in industrial countries in the post-war period to 1980 was 4.3% *per annum*, compared to 2.6% in other sectors.

Given the critical importance of achieving agricultural productivity gains many analysts have focussed on what generates technical change in agriculture and permits the continued exit of labour from the sector. Hayami and Ruttan (1971, 1985) and Binswanger and Ruttan (1985) developed the concept of 'induced technical change' in which an increasing price of labour driven by economic development in the rest of the economy promotes the development of labour-saving technologies in agriculture, such as mechanization. The growing demand for food created by an expanding non-agricultural population and by economic growth generates pressures to increase production from the available land base and this stimulates the development and adoption of land-saving technologies (such as fertilizer and other yield-enhancing agro-chemicals). These two forms of technical change permit agriculture to meet an expanding demand for both factors and agricultural output in the rest of the economy.[1] The importance of land *versus* labour saving technologies in increasing productivity has depended on resource endowments in particular countries. However, the "industrialisation" of agriculture – increased reliance on the use of substantial quantities of purchased inputs – has been a major aspect of the development of the sector and an important part of the process of increasing productivity. Technological change continues to play a key role in the development of the agricultural sector and its ability to provide increasing quantities of food and agricultural raw materials to satisfy the needs of an expanding world population (Ruttan, 2002).

The magnitude of some of the changes that have occurred in agriculture can be illustrated by reference to the United States. In 1900 41% of the total workforce was employed in the sector. This had declined to 16% by 1945 and to 4% by 1970 (Dimitri *et al.*, 2005). During the same period roughly 22 million draught farm animals (oxen, horses and mules) were almost entirely replaced by 5 million tractors – freeing-up a substantial amount of land that had been devoted to growing feed for these animals for the production of other crops. In 1910, 80% of all the inputs used on farms came from farms, *e.g.*, seed, livestock and livestock feed, by 1970 the proportion had declined to 66%, and in 2008 the figure was 59%.[2] The fall in the on-farm input percentage reflects a substantial increase in the use of manufactured inputs, particularly fuel, fertilizer and lime, and agrochemicals. Total factor productivity (TFP) in US agriculture increased at an average rate of just over 1.5% *per annum* over the period 1948-2008. With respect to the period 1947-85, Jorgenson and Gollup (1992) show that TFP growth in agriculture accounted for over 80% of total agricultural output growth and that this was four times higher than the corresponding productivity growth rate in the rest of the economy.

Similar substantial structural changes in agriculture and growth in productivity have been documented for Europe (Campbell and Overton, 1991) and in other regions (Hayami and Ruttan, 1971 and 1985). In a study of agricultural productivity in more than 90 countries, Coelli and Rao (2005) conclude that the mean rate of growth in TFP averaged 1.02% *per annum* over the period 1980-2000, which is quite high considering that the group included a number of developing countries in which agricultural productivity

1 In addition to supplying labour to the rest of the economy, an increasingly productive and profitable agricultural sector can also be a source of capital for other sectors.

2 These figures are computed from the online edition of the Historical Statistics of the United States and the Farm Income and Costs database of the Economic Research Service, United States Department of Agriculture (USDA) (www.ers.usda.gov).

growth was lagging during this period. This estimate also compares favourably with the average rate of growth in TFP of 0.96% *per annum* for the economy as a whole in 23 OECD countries for the period 1975-1990[3] (Maudos *et al.*, 1999).

2.2. The implications of agricultural growth for consumption

As agriculture becomes more productive and its output increases there is a tendency for food prices to decline relative to those of other goods and services. The income elasticity of demand for food, which is less than unity in all but countries at a very low level of economic development, tends to fall in value with economic growth. As consumers become wealthier they allocate more of their expenditures to non-agricultural goods and services. At the same time high rates of productivity growth in the agricultural sector put increasing supplies of products onto the market and this tends to drive down prices. The price elasticity of demand for food also tends to fall as incomes increase – consumers become less responsive to changes in food prices as their total consumption increases with higher incomes – and this adds to downward price pressures.

The influence that productivity growth can have on food prices is illustrated by the pattern for two important agricultural commodities – maize and wheat – in the United States (Figure 1). Given the importance of the United States as a producer and exporter of these basic commodities, trends in US prices are often reflected in those in other countries. The real (inflation-adjusted) prices of these commodities in 2000 were 21% and 25%, respectively of the corresponding levels in 1945. There have been some periods of marked upward movements in prices, most notably in the early 1970s, and prices in recent years have strengthened from those seen in 2000. Nevertheless in 2009 the real price of maize was 32% of the corresponding 1945 level and that for wheat was 34% of the 1945 value. During the period included in the graph the average annual yield of wheat per hectare in the United States increased by a factor of 1.6; while that for maize increased by a factor of 4. These substantial increases in yields demonstrate the impact that technological change and improved management practices have had on productivity and prices in US agriculture.

Expenditure elasticities for food tend to be higher than income elasticities, since higher incomes tend to generate increased demand for higher quality and more expensive food products. As a result *per capita* expenditure on food tends to increase over time (after adjusting for inflation), for example, in the United States *per capita* expenditure on food increased by roughly 40% in real terms between 1960 and 2009.[4] As their incomes increase consumers demand products with higher added value beyond the farm-gate, such as prepared foods. Traill (1998), for example, notes the importance of the growth in demand for convenience and higher value-added foods for the evolution of food consumption patterns in Europe. Gracia and Albisu (2001) note a similar tendency towards the "homogenization of food consumption patterns" in Europe, although differences in preferences and food habits are still important. As consumers shift their preferences with rising incomes, the share of the total value-added in the food system received by farmers tends to decline. In 1970, for example, farmers in the United States received 32% of the value of total expenditure on food. The remaining 68% was absorbed by marketing expenses beyond the farm-gate such as packaging and transportation and, most notably, by labour costs incurred in processing and delivering foods to consumers (29% of total expenditure). By 2006 (the most recent year for which data are available), the farm share had fallen to 19% and the share of labour expenses beyond the farm-gate had risen to 39%. This

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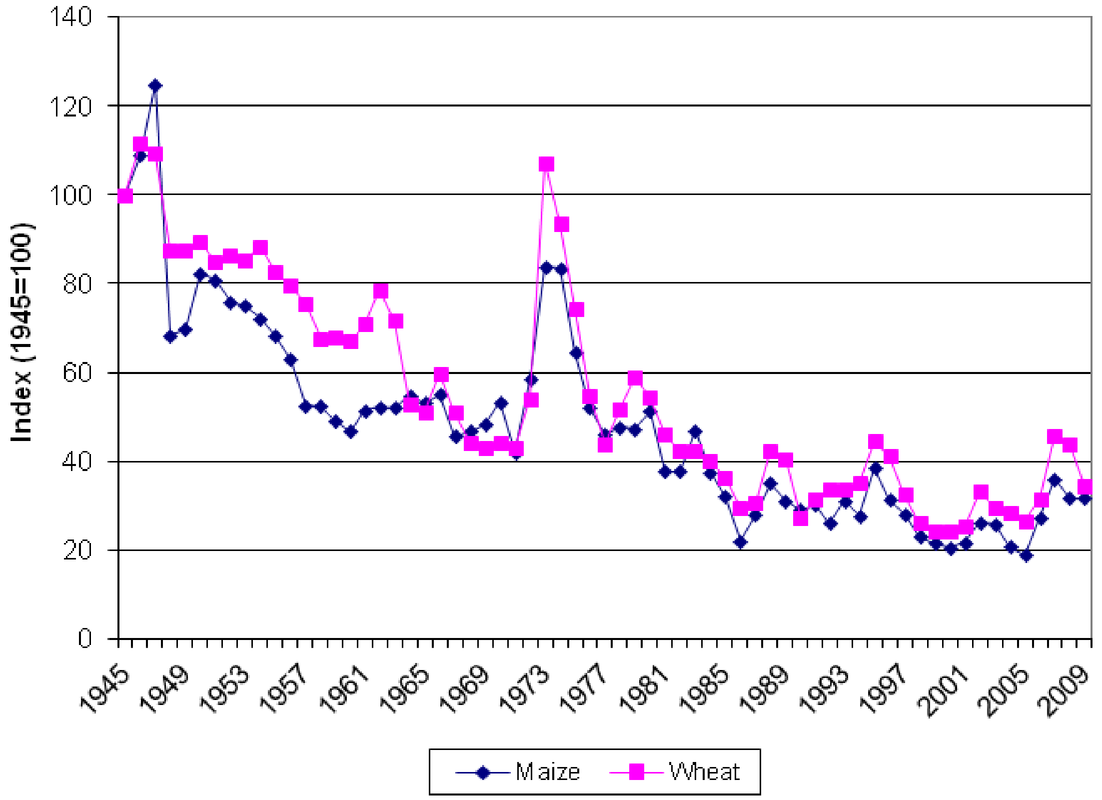
3 The countries included were Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

4 Unless otherwise indicated, figures on aspects of food consumption in the United States are calculated from data available through the online "Briefing Rooms" on Food CPI and Expenditures and the Food Marketing System at the Economic Research Service, USDA (www.ers.usda.gov).

illustrates the tendency for the expansion of value-added activities downstream from farms to generate increased economic activity and employment.

Another key development is that expenditure on food away from the home tends to increase with economic growth. Individuals and households tend to economise on the time spent in preparing food in the home and to use purchases food outside the home to meet a greater proportion of their needs. In the United States, for example, expenditure on food consumed outside the home represented roughly 25% of consumers' total food expenditure in 1970 (Lin *et al.*, 1999). In 2009, the corresponding figure was roughly 49%. Most of the 40% increase in real *per capita* expenditure on food in the United States since 1960 noted earlier can be attributed to the growth in consumption outside the home.

Figure 1. Real farm prices of maize and wheat in the United States, 1945-2009



Source: Seasonal average price data from National Agricultural Statistics Service (NASS) online database. Deflator is the US producer price index for all commodities from the Bureau of Labor Statistics (BLS) online database.

Despite such structural changes over time, which may differ in magnitude across countries, there is a broad tendency for expenditure on food to decline in relative terms with economic growth – such that the share of consumers' disposable income spent on food falls. In the United States, for example, in 1930 24% of disposable income was spent on food (both at home and away from home consumption). By 1970 the proportion had fallen to 14%. The most recent figure (2009) is less than 10%. Similar trends are apparent from historical data for other OECD countries (Blandford, 2000). Connor (1993) analyzed changes in food expenditure patterns in both North America and Western Europe and concluded that substantial convergence was occurring in both total food expenditure and the composition of expenditure. The tendency for the expenditure share to fall as incomes rise is important for economic activity in other sectors. As consumers are able to spend relatively less of their income on food they have more disposable income to spend on other goods and services and the demand for those goods and services will be higher.

2.3. The current economic role of agriculture

The agricultural sector in OECD countries is tending to shrink relative to the rest of the economy, both in terms of its contribution to gross domestic product (GDP) and employment. Declining output prices brought about by high rates of productivity growth and sluggish demand for food mean that agriculture's share of gross domestic product tends to decline over time.[5] For example, in 1945 agriculture accounted for roughly 7% of GDP in the United States; in recent years the figure has been below 1% (Dimitri *et al.,* 2005). Even in regions that are classified as predominantly rural in OECD countries the share of agriculture in regional GDP and employment has tended to decline, although in some countries (Poland, Portugal, Turkey and Korea), agricultural employment still accounts for more than 25% of total employment in such regions (OECD, 2010b).

Table 1 shows the current situation in OECD countries with respect to agriculture's contribution to gross domestic product and total employment, and the share of consumer expenditure devoted to food. The contribution of agriculture to GDP ranges from 0.2% in Luxembourg to 5.8% in New Zealand. The median value for the OECD countries is 4%. The GDP figures include hunting, forestry and fishing and overstate to some extent the agricultural contribution to national economic activity. Agriculture's contribution to total employment ranges from 1.4% in Luxembourg to 27.4% in Turkey. The median value for OECD countries is 6.8%. Finally, the share of consumer expenditure devoted to food (the figures also include non-alcoholic beverages) ranges from 6.8% in the United States to 27.4% in Turkey. The median value for OECD countries is 12.8%.

It is important to note that the contribution of agriculture to total employment is understated by the figures in Table 1. Those figures only take into account labour directly employed in the sector. Additional jobs are generated in upstream and downstream industries by agricultural activities. For example, one study estimated that although US agriculture accounted for roughly 1% of total domestic employment and less than 1% of GDP in 1996, the total food and fibre system accounted for 13% of GDP and 17% of total employment (Lipton *et al.,* 1998). Upstream industries providing inputs to farmers accounted for 4% of the additional GDP, while downstream industries (transportation, processing and retailing) accounted for the remaining 8%. It has been observed that for the EU-12 in 1994 the food industry was the largest single industry in terms of output, and the second largest in terms of employment (Traill, 1998). While it is debatable exactly how much of the additional GDP and employment generated by the food system is inextricably linked to domestic agricultural activity (for example, some food processing activities, and to an even greater extent food retailing and food service activities, could be serviced by imports rather that from domestic agricultural products) it is clear that agriculture and related sectors generate a substantial amount of economic activity and employment in many OECD countries.

[5] Countries that have a comparative advantage in agricultural products, such that they develop significant export markets, may experience a smaller relative decline in the economic importance of the agricultural sector, but the secular tendencies described still apply.

Table 1. Agriculture in the economy of OECD countries

Country	Year	Agriculture's share of GDP	Year	Agriculture's share of employment	Year	Share of consumer expenditure on food
Australia	2008	2.3%	2008	3.3%	2008	10.7%
Austria	2009	1.4%	2008	5.6%	2007	11.0%
Belgium	2009	0.8%	2007	1.8%	2008	12.6%
Canada	2008	1.5%	2008	2.4%	2008	9.1%
Chile	2009	3.4%	2008	11.5%	2008	17.3%
Czech Rep.	2009	2.3%	2008	3.3%	2008	17.0%
Denmark	2009	1.4%	2008	2.7%	2008	11.2%
Finland	2009	2.7%	2008	4.5%	2008	12.5%
France	2009	2.0%	2008	3.3%	2009	13.6%
Germany	2009	1.1%	2008	2.3%	2008	11.1%
Greece	2009	2.7%	2007	11.6%	2007	17.0%
Hungary	2009	3.4%	2008	4.5%	2008	17.9%
Iceland	2008	3.5%	2008	4.0%	2009	12.8%
Ireland	2009	1.6%	2008	5.8%	2008	9.4%
Italy	2009	1.8%	2008	3.9%	2008	14.9%
Japan	2007	1.7%	2008	4.2%	2007	14.6%
Korea	2009	2.8%	2008	7.2%	2009	13.0%
Luxembourg	2009	0.2%	2007	1.4%	2008	10.2%
Mexico	2008	2.5%	2008	13.0%	2008	24.2%
Netherlands	2009	1.9%	2008	2.6%	2008	11.3%
New Zealand	2008	5.8%	2008	7.0%	2008	17.6%
Norway	2009	1.3%	2008	2.8%	2007	12.0%
Poland	2009	2.7%	2007	14.7%	2008	20.1%
Portugal	2009	2.4%	2008	11.5%	2006	16.7%
Slovak Rep.	2009	3.4%	2008	4.0%	2008	17.7%
Spain	2009	2.2%	2008	4.4%	2007	14.3%
Sweden	2009	1.8%	2008	2.2%	2009	12.8%
Switzerland	2008	1.1%	2008	4.0%	2007	10.4%
Turkey	2009	1.9%	2008	23.7%	2009	27.4%
UK	2009	0.6%	2008	1.5%	2008	8.8%
US	2007	0.9%	2007	1.4%	2008	6.8%
OECD Median		1.9%		4.0%		12.8%

Notes: GDP figures relate to GVA at market prices; agriculture includes hunting, forestry and fishing. Food expenditures include non-alcoholic beverages.

Source: OECD, Employment figures from the Annual Labour Force Statistics (ALFS) dataset, except for France, Chile and the US, which are from the Annual National Accounts dataset. GDP and consumer expenditure figures are from the OECD, Annual National Accounts dataset.

In many regions in OECD countries there has been increasing interest in the development of specialty and niche products and "local foods". This has been driven by a range of factors including the desire to preserve local farming systems, increase local value-added in the food and agricultural sector, diversify farming activities, reduce the transportation of food products, develop alternative production systems (*e.g.,* organic), and increase the availability of fresh produce. In the United States, for example, the number of farmers' markets that deliver food directly to local consumers has been expanding rapidly. There are currently over 6 000 such markets, compared to less than half that number in 2000.[6] The development of local foods can be stimulated by efforts to develop tourism and new delivery systems to consumers, for example, the development of contracts between farmers and consumers for the delivery of fresh produce (*e.g.,* community-supported agriculture in the United States). Such developments are helping to increase the economic activity and employment associated with agriculture in some areas and to offset the tendency for secular decline in the sector's contribution to income and employment.

In summary, despite a declining contribution to GDP and employment in many OECD countries, agriculture still plays an important role in the economy. This role is partly due to the economic activity that is generated in sectors linked to agriculture, and partly to the role that agriculture plays in keeping food prices low so that consumers can use more of their disposable income to purchase other goods and services. The economic impact of agriculture is clearly larger than might appear at first sight, and consequently the implications of green growth policies that affect the sector might also be more significant. Agriculture also plays a major role in the use and management of natural resources.

2.4. The environmental role of agriculture

Agriculture is an extremely important sector when viewed from an environmental perspective. It is a major user of land and water. It can have a significant impact on environmental quality, through its effect on these resources as well as on air quality and biodiversity. In contrast to many other sectors where the sole focus of attention is on negative environmental externalities associated with production, agriculture can also be a source of positive externalities and a supplier of public goods. Consequently, analysis of the impact of existing or alternative policies that focus on green growth objectives is more complicated for agriculture than for many other sectors because of its potential to make both positive and negative contributions to environmental quality.

Agriculture occupied roughly 37% of the total land area of the OECD countries in 2007. If forestry is added to this total the percentage is 68%. Forestry can be viewed to be a closely related industry to agriculture particularly in the context of the green economy – both industries are likely to be affected by policies that seek to achieve environmentally sustainable economic growth and the improved management of land and water resources. Figure 2 shows the percentage of total land area occupied by agriculture and by agriculture and forestry combined in individual OECD countries. In 22 of the 31 countries the combined agriculture/forestry share is equal to or in excess of 75% of the total land area. In only four countries (Canada, Chile, Iceland and Norway), which have significant areas of land in climatically extreme zones, is the figure less than 50%. As noted in OECD (2008a) the majority of OECD countries have experienced a decline in the area devoted to agriculture in recent decades, but with an increasing volume of output per hectare – reflecting the role of productivity growth in the sector. Soil loss has been an on-going issue in agriculture. Analysis by the OECD on trends in soil erosion due to wind and water suggests that there has been an improvement or stabilisation in soil erosion in OECD countries with an increase in the share of agricultural land in the tolerable erosion risk class and a decline in areas with moderate to severe erosion (Table 2).

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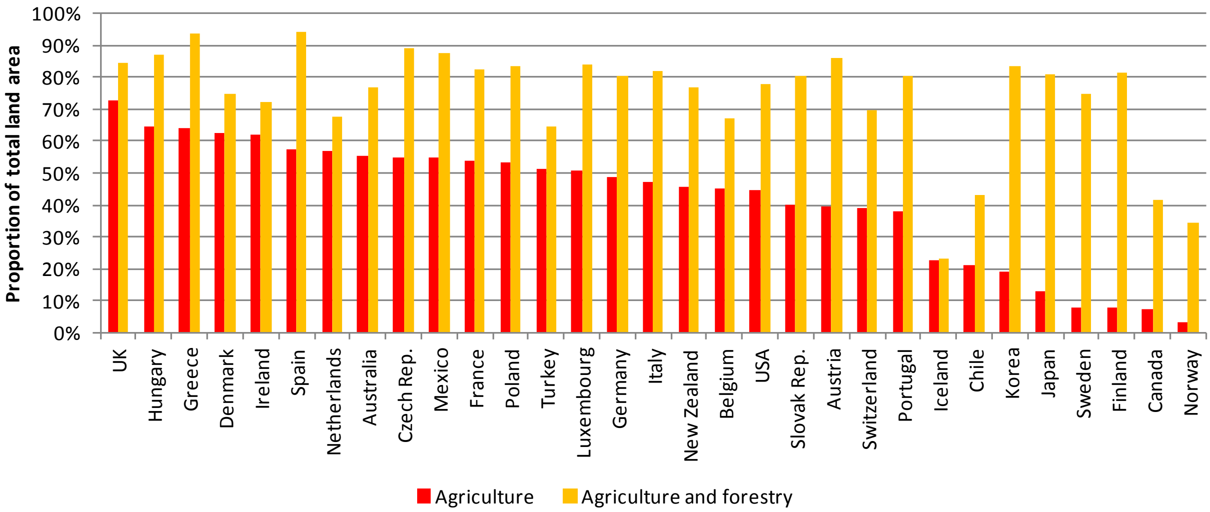
6 USDA Agricultural Marketing Service survey of operating farmers' markets, www.ams.usda.gov.

Figure 2. Use of land by agriculture and forestry in OECD countries, 2007



Source: FAOSTAT.

OECD agriculture is a major user of water, accounting for an estimated 44% of total use in 2001-03 (OECD, 2008a). Water use in agriculture appears to be increasing, primarily through an expansion in irrigated area (Table 2). Agriculture is becoming more reliant on water drawn from aquifers and this is creating an increasing risk of depletion of groundwater supplies. With respect to air quality, it is notable that agriculture is a significant source of acidifying emissions (ammonia), potential ozone-depleting substances and greenhouse gases. In the latter two cases, the 8% share of total emissions for the OECD countries as a whole in Table 2 can be contrasted with the median value for the share of agriculture in GDP of roughly 2% in Table 1.

As noted earlier, agriculture is a significant user of agro-chemicals and other purchased inputs, including energy. Energy use in OECD agriculture (on-farm use only) is roughly in-line with its contribution to GDP at around 2% of total energy use. On-farm energy consumption has been increasing more slowly than in the OECD economies as a whole (3% compared to 10% over the period 1990-02 to 2002-04). However, agricultural production generates energy consumption in a range of related sectors – including those that supply inputs, transportation, and food processing. A recent analysis for the food system as a whole in the United States has concluded that the food-related share of the national energy budget was roughly 16% in 2007 (Canning *et al.*, 2010).

With respect to the nutrients contained in the agro-chemicals used in the production of crops, OECD (2008a) provides a broader analysis of the amounts of nitrogen and phosphorous potentially released to the environment by examining the gross nutrient balance, *i.e.*, the difference between the total quantities of these nutrients from all sources entering and leaving the agricultural system. On that basis, the surplus in the nutrient balance (excess of total nutrient supply over apparent use) declined for both nitrogen and phosphorous between 1990-92 and 2002-04, even though in the former case the consumption of inorganic nitrogen increased. Similarly, total pesticide use (measured in terms of active ingredients) was found to have declined, although there was marked variation across countries. Excessive nutrient release can have an impact on water quality. The OECD study notes that for many OECD countries the share of agriculture in the total pollution of surface water by nitrates is over 40% (OECD, 2008a, p. 102). It also observes that "nearly a half of OECD countries record that nutrient and pesticide concentrations in surface and groundwater monitoring sites in agricultural areas exceed national drinking water recommended limits."

(p. 18). Overall, however, the OECD study concludes that "with farm production increasing more rapidly than the use of most inputs, this suggests that input efficiency has improved and as a consequence pressure on the environment has eased" (p. 16).

Table 2. Summary of environmental trends in OECD agriculture

Factor	Summary of trends	Explanatory notes
Soil	Improvement or stability in soil erosion from both water and wind. Increase in the share of agricultural land in the tolerable erosion risk class and reduction in areas with moderate to severe erosion risk.	Areas of agricultural land affected in terms of different classes of erosion, *i.e.*, tolerable, low, moderate, high, severe.
Water	Agricultural water use rose by 2% compared to no change for all users from 1990-92 to 2001-03. Increase in irrigated area was 8% compared to a reduction in total agricultural area of 3%. Limited data indicate that an increasing share of supplies is being drawn from aquifers – agriculture's share in total groundwater utilisation was over 30% in one-third of OECD countries in 2002.	Agricultural water use accounted for 44% of total water use in OECD countries in 2001-03.
Air	Farming accounted for 22% of total OECD acidifying emissions, 8% of the use of potential ozone-depleting substances, and 8% of greenhouse gases in 2002-04. Total ammonia emissions grew by 1% from 1990-92 to 2001-03, but there was a reduction in overall acidifying emissions. GHG emission decreased in most countries but there were increases of over 5% in some countries.	Agriculture accounts for over 90% of anthropogenic ammonia emissions; nearly 75% of methyl bromide use, 70% of nitrous oxide, and over 40% of methane emissions.
Nutrients	Decline in nutrient balance surplus of 4% for nitrogen and 19% for phosphorous between 1990-92 and 2002-04. Use of inorganic nitrogen fertilizer rose by 3%, but that of inorganic phosphate declined by 10%	Measure relates to gross nutrient balance, *i.e.*, the difference between the quantity of nutrients entering and leaving the agricultural system.
Pesticides	Total pesticide use declined by 5% between 1990-92 and 2001-03 with marked variations across countries.	Measured in terms of pesticide use (or sales) in terms of tonnes of active ingredients.
Energy	On-farm energy consumption increased by 3% between 1990-02 and 2002-04 compared to 19% for all sectors.	Share of farming in total OECD energy consumption was around 2% in 2002-04.
Biodiversity	Increasing diversity of crop varieties and livestock breeds in production (1990-2002). Decline in farmland bird populations from 1991-2004, but less pronounced than in the 1980s.	

Source: OECD (2008), *Environmental Performance of Agriculture in OECD Countries since 1990,* OECD, Paris.

Agriculture is a major source of global greenhouse gas (GHG) emissions, accounting for at least 10-12% of total anthropogenic emissions in 2005 (Wreford *at al.*, 2010). Methane (CH_4) produced by animals through enteric fermentation or manure and from rice cultivation accounts for roughly 54% of agriculture's total emissions (CO_2 equivalent) with the balance in the form of nitrous oxide (N_2O) released through a range of soil and land management practices. Agriculture accounts for roughly 60% of global emissions of nitrous oxide and roughly 50% of total methane emissions.

The conversion of land to agriculture has been identified as a significant factor, both in terms of the sector's contribution to GHG emissions and a source of environmental damage (OECD, 2008c). However, if land that is already employed in agriculture is managed appropriately this can make a positive environmental contribution in such areas as GHG reduction (sequestration) and biodiversity. The measurement of such contributions is difficult. For example, relatively few OECD countries regularly monitor biodiversity. According to the Convention on Biodiversity (www.cdb.int) there are three types that should be considered: 1) genetic; 2) wild species; and 3) ecosystem diversity. OECD (2008a) assesses the available information on these (Table 2). It notes that while there has been some increase in genetic diversity in crop varieties and livestock breeds in some countries (associated primarily with business objectives relating to diversification, niche products, and the effects of agri-environmental policies) the balance of evidence points to a decline in biodiversity, particularly among wild species and in farm ecosystems. Of particular concern is a demonstrated decline in farmland bird populations in just over half of the countries that monitor these, although there is some evidence of a recovery more recently in some countries. This may be associated with the introduction of conservation schemes and changes in management practices under agri-environmental programmes (p. 19).

Analysts have attempted to quantify the total external costs generated by agricultural activity in some OECD countries. Tegtmeir and Duffy (2004) draw upon a range of valuation of studies for environmental externalities in the areas of natural resources, wildlife and ecosystem diversity, and human health to derive an estimate for the United States. They estimate that for 2002 external costs ranged from USD 5.7 billion to USD 16.9 billion; much of the uncertainty in valuation associated with the damage caused by soil erosion. These estimates are equivalent to roughly 3-8% of the value of production at the farm level in that year. Pretty *et al.* (2000) provide an annual estimate for UK agriculture for the period 1990-96 of GBP 2.3 billion – an amount equivalent to 13% of gross farm returns. Their range of estimates is GBP 1.1-3.9 billion depending on assumptions in valuing damage. The largest total contribution to the cost is associated with GHG emissions. More recent data for the period 2000-08 suggest that the average value of damage from agricultural activities in the UK (measured at current prices) was roughly GBP 2.3 billion per year[7] (DEFRA, 2010). In this more recent dataset, estimates are also derived for the value of positive externalities and public goods provided by UK agriculture (primarily landscape and biodiversity benefits). These averaged roughly GBP 1.6 billion annually over the period, giving a net contribution from positive and negative externalities of roughly GBP -0.7 billion per year.[8]

There is certainly increasing awareness in many OECD countries of how changes in agricultural management practices can potentially contribute to improving environmental quality (with respect to the *status quo*), both by modifying production methods to reduce negative externalities, such as water pollution, and enhancing the contribution to positive externalities and the provision of public goods, such as increasing wildlife habitat and biodiversity, water management (groundwater recharge and flood prevention), and the provision of amenities. The potential for not only reducing GHG emissions in agriculture, but also sequestering carbon and contributing to the production of green energy are also areas in which agriculture and the related land-based forestry industry are both involved.

In addition to environmental issues, a series of other concerns have become more prominent in many OECD countries in the debate over the role of agriculture in the economy and society. These concerns include such issues as food quality and safety, animal welfare, the use of certain types of new technology (*e.g.,* biotechnology and nanotechnology), diet and health issues (in particular, the growing problem of obesity in many OECD countries), and the implications of increases in scale in farming and concentration in the food industry. Many of these concerns relate to the on-going process of technological and structural change in agriculture. Addressing these concerns, as well as those relating specifically to the environment,

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7 This does not include an estimate for the cost of damage to human health from microorganisms or other disease agents which was incorporated by Pretty *et al.* (2000). If those are subtracted, the comparable figure for the early 1990s from their study would be roughly GBP 1.5 billion.

8 The estimates demonstrate how externalities can vary regionally. Separate figures derived for Scotland suggest that the value of benefits exceed the cost of damage, whereas costs exceed benefits in England, Wales and Northern Ireland.

is part of the challenge faced by policy makers in achieving a sustainable food and agricultural system that can contribute positively to achieving green growth objectives.

3. Green growth and the agricultural sector: Challenges and opportunities

Having reviewed the current situation in terms of the economic and environmental contributions of agriculture we now turn our attention to the future. As a major provider of one of the essentials of life (food) and an industry that is heavily reliant on climatic conditions, the outlook for food demand and the potential impact of climate change are particularly important for pursuing a green growth strategy in the sector.

3.1. Increasing demand for food and agricultural raw materials

The United Nations projects that by 2050 the World's population be over 9 billion, compared to less than 7 billion currently, an increase of roughly one-third (UN, 2010). It is estimated that in order to achieve a global average food consumption of 3 130 kcal per person per day by 2050 an additional billion tonnes of cereals and 200 million tonnes of meat would need to be produced annually (compared to levels in 2005/07) (Bruinsma, 2009). Meeting these targets will require a combination of higher yields, higher cropping intensity, and some expansion in agricultural land use where feasible (primarily in sub-Saharan Africa and Latin America). The land equipped for irrigation would need to expand by some 32 million hectares (11%) and harvested irrigated land by 17%, primarily in developing countries. As noted earlier, this carries environmental risks. For example, OECD (2005) observes that an increase in global production of food crops by 16%, relative to 2005, will be a major factor in reducing biodiversity, mostly due to the conversion of grasslands and forested area to farmland. Bruinsma (2009) estimates that with the projected expansion in output by 2050 water consumption in agriculture will increase by almost 11% relative to 2005/07. It is clear from these estimates that the growth in the world's population will place increased pressure on agriculture to supply food and raw materials, on the natural resources used by the sector, and on environmental quality. Achieving green growth in agriculture while meeting the demands of an expanding world population will pose a major challenge.

Global demand for agricultural products has been strong in recent years, partly as a result of dietary changes, particularly an expanding demand for animal products associated with economic growth in developing countries, and the increased use of grains and oilseeds to produce so-called first generation biofuels. Expanded production of ethanol and biodiesel from agricultural crops has been driven by a range of policies including subsidies and tax credits, and blending or consumption mandates or targets. It is unclear how much additional demand for agricultural crops will be generated by further expansion of biofuel use. Considerable efforts are being made to develop alternative feedstocks to the grain, oilseeds and sugar crops that are the primary source of first generation biofuels. Some of the second generation alternatives, such as cellulosic biomass from waste agricultural or forestry products may simply increase the efficiency with which current biomass production is used. However, the use of other feedstocks such as grasses (*e.g.,* Miscanthus) and short rotation woody crops (*e.g.,* willow) could exert additional pressure on land and water resources.

Strong demand, in combination with a number of other factors such as drought in several key grain-producing regions, resulted in a virtual doubling of world prices for wheat, coarse grains, rice and oilseed crops between 2005 and 2007 (OECD, 2008b). While such dramatic changes in prices have been unusual in recent history there is uncertainty about the future trend in prices and price variability. As noted earlier, productivity growth has played a major role in allowing agriculture to meet the food and raw material needs of an expanding global population at reasonable prices and to contribute to economic growth in the rest of the world economy. The future rate of productivity growth in agriculture will be a key factor determining whether food prices and expenditure shares can be kept at reasonable levels in the face of higher demand. The nature of technological change will also be a key factor in determining whether green growth objectives can be achieved in meeting this demand.

Alston *et al.* (2009) document a slowdown in global productivity growth in agriculture since the early 1960s (Table 3). Average annual increases of 2-3% in key crops such as maize, rice, soyabeans, and wheat from 1961-90 have been replaced by average annual increases of around 1% or less during 1990-2007, with the exception of maize. The growth in output per unit of land has also declined, but the productivity of labour has increased. The authors point to a significant reduction in publically funded research and development over the period as a major factor in the slowdown in productivity growth in agriculture. Whether or not this is the case, their view of declining productivity is consistent with assumptions in the Food and Agriculture Organization's (FAO) projections of future availability of food, *i.e.*, that yields of major crops will increase more slowly in the future than in the recent past (Bruinsma, 2008). There are contrasting views, however. Fuglie (2010) concludes that although the rate of growth in world agricultural output has declined since the 1960s the rate of increase in TFP has actually accelerated. He attributes the lower rate of growth in output to the effects of low commodity prices which discouraged the use of resources in the agricultural sector.

Table 3. Recent trends in productivity growth in world agriculture

	1961-1990	**1990-2007**[1]	
	Average annual increase %		1990-2007 rate minus 1961-1990 rate
Yields			
Maize	2.20	1.77	-0.43
Rice	2.19	0.96	-1.23
Soyabeans	1.79	1.08	-0.71
Wheat	2.95	0.52	-2.43
Output per unit			
Land	2.03	1.82	-0.21
Labour	1.12	1.36	0.24

1. Averages for land and labour are for 1990-2005.

Source: Alston, J.M., J.M. Beddow, and P.G. Pardey (2009), "Agricultural Research, Productivity, and Food Prices in the Long Run", *Science*, Vol. 325, pp. 1209-1210. Supplementary tables.

The implication of recent analysis seems to be that while it seems feasible that global agriculture will be able to meet future demands for food to the middle of this century, although this will carry environmental risks, its ability to do so may require somewhat higher prices for food than we have been used to, particularly if the stream of new technology and technical innovations does not keep pace with the growth in demand. The prospect for higher average prices for wheat, coarse grains and oilseeds over the coming decade is foreseen in a recent agricultural outlook report of the OECD and the FAO (OECD, 2010c).

Buoyant demand and higher prices are clearly advantageous to those employed in the agricultural industry. The sustained downward pressure on prices that we have witnessed in recent decades has made it difficult for many farmers to operate profitably and has stimulated substantial structural adjustment. Many farmers have exited the industry and remaining farms have grown in size. These tendencies are unlikely to disappear even if prices are firmer than in the past, but the profitability of farming could well increase. The prospect of higher prices will generate concern among poorer consumers, particularly in developing countries. As we seen in the recent past, food security concerns can trigger measures to protect domestic agriculture and to restrict trade. Such measures can add to international price volatility. Even in wealthy countries, consumers who have become used to spending a declining proportion of their income on food, may have to become accustomed to higher prices and greater price volatility in the future.

3.2. Climate change

A recent assessment by the Intergovernmental Panel on Climate Change (Parry *et al.,* 2007) shows a mixed picture for the impact of climate change on agriculture (Table 4). Moderate increases in average global temperatures (1-3^{o}C), combined with higher concentrations of carbon dioxide and associated rainfall changes could have a small beneficial impact on crop yields in mid- to high-latitude regions, but are likely to reduce yields in low-latitude regions. Global average temperature increases in excess of 3^{o}C are likely to result in lower yields in all regions. The results from a range of modelling studies suggest that temperature increases above 3^{o}C could result in upward pressure on world cereal prices (Parry *et al.,* 2007). As a result of climatic change, some regions, particularly Sub-Saharan Africa, could experience a significant increase in the risk of hunger. Perhaps of even greater significance than the long-run impacts on yield (which are fairly uncertain given the current state of knowledge), we can be relatively confident that with global warming there is likely to be an increase in the frequency of extreme climatic events, such as heat stress, droughts and flooding as well as increasing risks of fires and pest and pathogen outbreaks. These are likely to increase the variability of agricultural production in many regions, and quite possibly globally.

There are some management actions that farmers might take to deal the impact of projected climatic changes on their farming activities. These include: 1) adopting crop varieties that are more resistant to climatic stress and modifying the use of inputs (*e.g.*, fertilizer and water); 2) adopting improved practices for conserving and managing water; 3) altering the timing or location of cropping activities; 4) improving pest, disease and weed management practices and using species with greater resistance to pests and diseases; and 5) using seasonal climatic forecasting to reduce production risk. The IPCC estimates that the widespread adoption of these practices could provide an estimated yield improvement of up to 10% compared to yields without adaptation. Unfortunately, little analysis has been conducted of the global costs of adapting to climate change in agriculture (Wreford *et al.,* 2010).

As noted earlier, agriculture is a significant source of GHG emissions. One study estimates that in the absence of abatement measures, annual global emissions of GHG from agriculture are likely to increase by 30% by 2030 when compared to estimated levels in 2005 (McKinsey and Company, cited in Wreford *et al.*, 2010, p. 80). If steps are taken to reduce emissions from agriculture or in sectors closely related to agriculture this could pose a challenge for the sector. Increases in the price of energy, for example, would have an impact both through the direct effect on the costs of energy used on farms and through higher prices for agro-chemicals and services such as transportation. However, farmers can be adept at economizing on the use of inputs in response to higher prices. For example, a study of how US farmers adapted to higher energy and fertilizer prices in 2006 showed that 23% of commercial farms (the primary users of purchased inputs) reduced their usage of both energy and fertilizer in response to higher prices (Harris *et al.,* 2008). Lower usage of energy was achieved through such measures as employing machinery less intensively and servicing engines more frequently; lower consumption of fertiliser was achieved through the greater use of soil testing, changes in plant populations and the adoption of precision application methods. The study noted that farmers with the highest energy and fertilizer costs and the lowest net incomes were most active in adopting measures to reduce input usage, suggesting that when changes in input costs become significant for farm profitability farmers pay particular attention to addressing these. Furthermore, there is evidence that some of the measures that farmers could take to change their practices in order to reduce GHG emissions are actually win-win, in that they not only achieve reductions in atmospheric carbon (or its equivalent) but can also increase farm profitability (Wreford *et al.,* 2010).

Table 4. Projected impact of climate change on agriculture

Outcome	Level of confidence
Increase in crop yields in mid- to high-latitude regions with temperature increases of 1-3^{o}C but lower yields in low-latitude regions (also higher forestry productivity). Increases in temperatures above 3^{o}C to have a negative impact on yields in all regions.	Medium
Changes in the frequency and severity of extreme climate events have significant consequences for food (and forestry) production and for food insecurity.	High
Increasing benefits of adaptation to climate change with low to moderate warming.	Medium
Adaptation to place stress on water and other resources.	Low
Smallholders and subsistence farmers and pastoralists to suffer complex, localised impacts.	High
International trade in food and forest products projected to increase, with increased dependence on food imports for most developing countries.	Medium to Low

Source: Parry, M.L, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.) (2007), *Contribution of Working Group II to the Fourth Assessment Report on Climate Change, 2007*, Cambridge University Press, Cambridge, UK and New York, United States.

Agriculture (and related industries such as forestry) can make a positive contribution to the mitigation of climate change by acting as a carbon sink. Some changes in existing cultivation practices that help to sequester carbon, for example the use of conservation or low-till methods of crop production, can increase production costs because more chemical inputs are required and yields may fall (Manley *et al.,* 2003). Furthermore, changes in land use, such as the conversion of cropland to permanent pasture or forest, may add to the pressure on remaining agricultural land to supply the growing demand for food and agricultural products. Consequently, trade-offs may exist between agriculture's potential role in climate change mitigation and the achievement of other environmental objectives (*e.g.,* improving water quality), as well as with the objective of meeting the food demands of an expanding world population.

3.3. Future resource demands – land, nutrients, water and energy

The growing pressures that are likely to be felt by agriculture as a result of increasing demand for its products and the potential effects of climate change are likely to be reflected in land markets. Land, particularly land that is highly productive, is likely to increase in value relative to other assets. During periods of strong agricultural growth agricultural land can be viewed as a desirable asset by both agriculturalists and non-agricultural investors. Hallam (2009) notes a recent rise in investment by a number of countries, such as the Gulf States in Africa and other locations, such as Brazil, Cambodia, Kazakhstan and Pakistan. The main form of investment is either the purchase or the long-term leasing of agricultural land for food production. Hallam notes that land under foreign control is a small proportion of the total land area in most cases and concludes that foreign investment can contribute to the USD 30 billion per year investment that will be needed by developing countries if they are double food production and meet the food needs of their growing populations by 2050. In any event, upward pressure on land prices is likely to be experienced in highly productive regions and this will add to pressure for more intensive land use. Farmers who are faced with high costs of servicing their investment in land will try to maximise net returns (excluding land costs) and this may lead them to apply more variable inputs, such as fertiliser and other agro-chemicals.

It is generally agreed that there will be sufficient supply of major crop nutrients, such as nitrogen and phosphorus for the foreseeable future (Keyzer *et al.,* 2009). However, the availability of several essential micronutrients (boron, copper, molybdenum and zinc) could become an issue as supplies become increasingly constrained by 2040-50. Higher prices and new technologies will be needed to recover such micronutrients for use in agriculture. Although global reserves of most other nutrients appear to be sufficient, there is likely to be growing pressure on supplies of some, for example, phosphates. The increasing demand for fertilizer and the limited availability of readily accessible sources of supply for some nutrients has stimulated mergers and acquisitions activity in this sector. Recently, for example, the largest mining company in the world (BHP Billiton) made a hostile take-over bid for the Canadian company PotashCorp, the largest potash mining company in the world.[9] At the beginning of 2010 the world's second-largest mining company (Vale) acquired the phosphate mining and fertilizer production assets of Bunge Ltd. and Cargill in Brazil. Earlier the company had purchased potash operations in Argentina and Canada from Rio Tinto.

The growth in the world's population will place increased pressure on available water supplies, even in the absence of climate change. Water scarcity is an increasing threat, particularly in developing countries. By 2030 it is projected that 47% of the world's population will live in areas with severe water stress, compared to 35% in 2005. The growth in demand for water for non-agricultural uses seems likely to place considerable stress on the availability of water for agriculture in such countries as China and India and could constrain their ability to increase food production. Studies differ on whether total water use in the sector will actually increase but it seems likely that there will be considerable pressure to improve the efficiency of water use (OECD, 2010d).

As noted earlier, agriculture's use of energy is roughly in line with its contribution to GDP in OECD countries – around 2%. However, the OECD food system as whole is both a more substantial contributor to both GDP and energy use. An examination of trends in the US food system concludes that while *per capita* energy use in the United States declined by 1.8% between 1997 and 2002, *per capita* food-related energy use increased by 16.4% (Canning *et al.,* 2010). When population growth over the period is taken into account, total US food-related energy use increased by 22.4%. These calculations take into account the energy involved in the manufacture of agricultural inputs, the production of crop and livestock products, food processing and packaging, the operation of refrigeration and disposal equipment in food retailing and foodservice establishments, and equipment in home kitchens. The principal reason for the expanded use of energy in the sector is a demand for convenience by consumers, in particular by consuming more prepared foods and a larger amount of food outside the home, both of which use more energy. Changes in food consumption patterns are affecting a large number of countries. While future increases in energy demand generated by agriculture *per se* may be relatively modest, further changes in lifestyles and food consumption patterns across the world could impose greater demands on global energy supplies. Reardon and Timmer (2007) document the transformation of the food system in developing countries, arguing that a profound retail revolution during the past decade is transforming food markets in much the same way as has already occurred in OECD countries. This transformation will have important implications for the energy intensity of the food system in developing countries and globally.

One popular concept relating to energy use and environmental externalities introduced into the debate on the functioning of the food system is that of "food miles" – the distance that food is transported from the point of production to the consumer (Paxton, 2004). Pretty *et al.* (2005) compare the estimated costs of food production externalities in UK agriculture to the costs of externalities associated with the transport of food to retail outlets and transporting food to consumers' homes.[10] When these other aspects are included, their estimate of the total cost of externalities associated with food consumption increases from GBP 1.5 billion (production externalities) to GBP 5.2 billion (production and delivery externalities). The authors note that even this higher estimate may be too low, given that it does not take account of

[9] The bid was blocked by the Government of Canada in November 2010 on the grounds that the change in ownership would not provide a net benefit to Canada.

[10] Also included are external costs associated with sea, internal water and air transport for imports, and waste disposal to landfill. However, these collectively account for less than 0.5% of the total external cost estimate.

externalities generated by energy consumption by processors, manufacturers and wholesalers for light, heat, refrigeration and transport, the disposal of food packaging, foods consumed by domestic pets, methane emissions from landfills and sewage waste, and the energy required for domestic food preparation. The estimated cost associated with transport from farm to retail outlets alone is GBP 2.3 billion or 55% higher than the estimated costs of production externalities.

Pretty *et al.* (2005) use a broad definition of external costs imposed by vehicle transport in their analysis, which include costs imposed by congestion, harm to health (noise stress, asthma), climate change (from greenhouse gases) and infrastructure damage. In contrast, Weber and Matthews (2008) focus on the life-cycle greenhouse gas (GHG) emissions associated with food production compared to long-distance distribution (food-miles) in the United States. The authors find that although food is transported long distances in general (the average delivery distance is 1 640 km with 6 760 km for the life-cycle supply chain) GHG emissions associated with food are dominated by the production and processing phases rather than distribution. They estimate that transportation as a whole represents 11% of the CO_2 footprint of the average US household's consumption of food, compared to 83% for production.[11] The authors also find that the various food groups exhibit significant differences in GHG intensity. For example, red meat is 150% more GHG-intensive than chicken or fish. On this basis the authors conclude that dietary shifts (substituting chicken and fish for red meat) can be more effective than local sourcing in reducing the food-related climate footprint.

Analysis by Saunders *et al.* (2006) of comparative energy efficiency in UK imports of agricultural products from New Zealand to those produced domestically supports the conclusion reached by Weber and Matthews that transportation is a relatively small contributor to total energy use in agriculture and that local sourcing of food may not necessarily lead to a reduction in total energy use and GHG emissions. Because they determine that the production of lamb is more intensive in terms of energy and other inputs in the UK than in New Zealand, Saunders *et al.* estimate that GHG emissions per tonne of product are more than three times larger for lamb produced in the UK than for lamb imported from New Zealand (calculated on a carcass weight basis), despite the fact that transportation from New Zealand to the UK accounts for 18% of the emissions for the New Zealand product. They also estimate that imported dairy products yield roughly half the emissions of domestically produced dairy products (calculated on a milk solids basis).

While these existing studies can be criticised on various grounds – their methodology, assumptions used and lack of hard data in some cases, it seems clear that the concept of food miles as a guide to policy is questionable. Simply because a product is transported a long distance from the point of production to point of consumption does not imply that it will generate a larger environmental footprint than a product that is produced and consumed locally. The environmental impact of food production and consumption is often difficult to determine and depends as much on the behaviour of consumers as it does on the actions of producers, processors and others who form part of the food system.

In recent years there has been a substantial growth in organic agriculture – agriculture that relies on minimal use of off-farm inputs and a management system that relies on techniques such as crop rotation, green manure, composting and biological pest control to maintain soil productivity and to control pests. Organic livestock production is based on organically-produced livestock feed and avoids the use of drugs and animal hormones. Organic production does not involve the use of genetically modified organisms. Some argue that a shift to organic methods could reduce negative externalities in agriculture, and increase positive externalities and the supply of public goods. One wide-ranging study of the literature in Europe concluded that with the possible exceptions of nitrate leaching and soil erosion, organic farming would exert no more pressure on the environment than conventional farming and in the area of biodiversity it

[11] The balance is contributed by non-transportation energy consumption in wholesaling and retailing.

would probably be superior (Stolze *et al.,* 2000). Wood *et al.* (2006) in a study of conventional and organic farms provide a comparative assessment of on-farm and indirect energy consumption, land disturbance, water use, employment, and emissions of greenhouse gases, taking into account both the direct (on-farm) and indirect (off-farm) effects of production. They conclude that despite the fact that on-farm energy use and GHG emissions were slightly higher on organic farms, the total effects (direct and indirect) were lower. The intensity of water use was also lower on organic farms. On this basis they conclude that the environmental performance of organic farms is superior to conventional farms. A further review focusing on studies in Europe of the linkage between organic farming and biodiversity concludes that three broad management practices: the prohibition on the use of chemical pesticides and inorganic fertilisers; sympathetic management of non-cropped habitats; and the use of mixed farming techniques that are generally associated with organic farming are particularly beneficial for farmland wildlife (Hole *et al.,* 2005). However, the authors also conclude that on the basis of the available evidence it is not possible to determine whether a whole-farm organic production approach provides greater benefits in terms of biodiversity than carefully targeted management prescriptions through agri-environment schemes for conventional agricultural systems applied to relatively small areas of cropped and/or non-cropped land.

Some studies have attempted to examine the environmental impact of shifting from conventional to organic systems in agriculture. Building on their earlier analysis, Pretty *et al.* (2005) estimate that applying organic production standards to UK agriculture in 2000 would have resulted in a reduction in the cost of environmental externalities from GBP 1.5 billion to less than GBP 0.4 billion. This calculation is based on the assumption of an unchanged structure of production, whereas in reality such a radical shift in production methods would make this unlikely. Examining the impact of a change from conventional agricultural systems to an organic system on output is extremely complex since the shift would not only influence the yield of individual crops, but also the mix of outputs due to the rotational requirements of an organic system.[12] Available evidence suggests that yields of some products, *e.g.,* fruit and vegetables, might not be significantly lower, although restrictions on the use of pesticides could affect product quality (*e.g.,* insect damage). On the other hand it would be difficult to obtain the same output of cereals and oilseeds under an organic system due to challenges in supplying sufficient crop nutrients and increased rotational requirements to control pests and disease. In a study of changing from conventional to organic agriculture in England and Wales using farm data for 2006, Jones and Crane (2009) conclude that if these factors are taken into account the change in technology would result in a 40% reduction in cereals production, 30% decline in milk output, and a 30% decline in pig and poultry production. On the other hand beef and sheep output would increase by 68% and 55%, respectively. Since ruminants are a significant source of GHG emissions in agriculture, this would probably result in a net increase in such emissions, which suggests there could be a trade-off between environmental outcomes. The authors estimate that total energy use would be lower, due to savings in the energy embodied in inorganic inputs, and that on-farm labour use would increase.[13]

While there will continue to be a debate between the proponents of conventional and organic agriculture on the potential for these system to feed the world, consumer demand, particularly in wealthier countries, is likely to continue to support the development of organic systems. However, it seems likely that at least for the foreseeable future we shall have to continue to rely on the use of non-organic inputs if

12 There would be additional effects on the output mix if output prices change as a result of the shift to organic methods.

13 In contrast, Rigby and Bown (2003) note a growth in energy consumption associated with the expansion of consumption of organic products in the UK due to a rapid growth in imports, *i.e.*, that lower direct energy consumption is being undermined by higher indirect energy consumption through a food-miles effect. If the energy efficiency of organic production is similar in the UK to that in suppliers of organic imports, unlike the New Zealand study of trade in conventional agricultural products, this observation would seem to be valid.

the expanding demand for food is to be satisfied. Despite this, there is certainly scope for the transfer of some organic production methods to conventional agriculture in order to reduce its environmental footprint. Examples include the greater use of organic fertilizers and composted materials (although this would require careful application to avoid water contamination), reductions in the use of pesticides through natural pest management approaches, and greater use of crop rotations to maintain soil quality and reduce disease risk. Rather than a complete shift to organic production, the challenge facing agriculture appears to be finding a middle way in which production techniques are modified to reduce their environmental impact, while maintaining increases in productivity.

Finally, it is important to note that while farmers in many parts of the world are extremely skilled in managing their resources, substantial potential exists to increase efficiency under existing technologies. Fischer *et al*. (2009) examine the "yield gap" for grains, *i.e.*, the gap between maximum yield under current technology and actual yield in 20 important producing regions around the world. They conclude that while the yield gap is tending to decline in many countries it remains substantial. They estimate average yield gaps for wheat and rice of 40% and 75%, respectively. In some cases – for example, maize in sub-Saharan Africa – current yields are roughly one-third of those that are technically possible. The authors believe that a gap of 25% would be consistent with sustainable production but that this can only be achieved if a range of issues is addressed, including infrastructural and institutional deficiencies affecting the use of inputs, attitude and skills issues among farmers, particularly in developing countries, and technical constraints. This observation is important since there can be a tendency to place undue emphasis on technology as the answer to increasing future productivity in agriculture. In reality, the solution lies in both technological and institutional improvements.[14]

Overall we can conclude that agriculture and the food system will face substantial challenges in meeting future consumer demands, while simultaneously economising on the use of increasingly scarce resources, moving towards a low-carbon economy, and dealing with other pressures, such as the demand for higher environmental quality and social concerns.

4. Policy dimensions of green growth in agriculture

The agricultural sector faces challenges in adapting to an economic environment oriented towards green growth. As indicated, agriculture has to continue to increase productivity, economise on the use of increasingly scarce resources, adapt production to become increasingly environmentally friendly, and adapt to climate change. At the same time, it needs to be able to contribute to improving environmental quality.

Some of the policies that will contribute to achieving these aims apply to the economy as a whole and some apply specifically to agriculture. A comprehensive framework for assessing green growth policies in the economy has been developed by de Serres *et al.* (2010) and this discussion draws upon aspects of that framework.

4.1. The macro-economic environment for agricultural adaptation to green growth

With technological change and the exit of labour, agriculture has become increasingly capital intensive. As such, its activities are strongly affected by the supply of capital and its cost. The costs of servicing investment in land, buildings and equipment can be high and sensitive to interest rates. For example, in the early 1980s as real interest rates rose in the United States the debt-to-equity ratio for the farm sector, which had typically been around 20% in the 1970s rose steadily and approached 30% by 1985. Many farms were under financial stress during this period and had difficulty in replacing ageing equipment

14 Increasing the potential supply of food does not ensure that hungry people will actually gain access to it. That complex issue is outside the scope of this paper.

and modernising their buildings. In recent years, with relatively low interest rates, the debt-to-equity ratio has fallen to less than 15% and farmers have faced a more favourable investment climate.[15]

The upstream sectors that provide inputs to agriculture and some of the downstream activities that handle its products, *e.g.*, transportation, storage and processing are also relatively capital intensive. If the food and agricultural sector as a whole is to keep pace with the growing demand for its products and to be able to supply these in the forms demanded by consumers the sector must have access to financing. The cost, riskiness and long-term nature of many of the investments in the development of new technologies in agriculture, such as new seed varieties, have been factors leading to increasing concentration in agricultural input industries worldwide. This tendency was reflected in the acquisition of 68 US seed companies by large multinational corporations from 1995-98, although subsequently some of the resulting combined companies became separate entities (King, 2001).

Another important characteristic is that the rate of profit in food and agriculture tends to be relatively low. For example, in the United States it is estimated that the average rate of pre-tax profit in the downstream part of the food industry in 2006 was roughly 5% which is modest in comparison to many other industries. The economy-wide average rate of profit for all corporate businesses (excluding earnings from overseas operations) in the United States was roughly 20% in 2006.[16] The low rate of profit means that the ability of the food sector to invest from retained earnings is less than in many other industries and its ability to mobilise investment resources through loans or public stock offerings is influenced quite strongly by the overall macroeconomic environment. The stability of that environment is therefore of considerable importance for the industry.

The need to respond to climate change is likely to impose additional demands on investment in agriculture and the food system, beyond those implied by the growth in world population. Msangi *et al.* (2009) examine the impact of climate change on infrastructural investment requirements in developing countries, focusing on the provision of irrigation and the expansion of rural roads to improve the distribution of inputs and outputs. Their analysis suggests that future needs in those areas will be substantial. The required expansion of irrigation infrastructure and improvement in its efficiency is estimated to generate an additional demand for expenditure of more than 70% above baseline levels (that required in the absence of climate change); the projected increased need for expenditure on rural roads is roughly 90%.

The development of infrastructure for agriculture and the food system in developing countries is a particularly pressing issue in order to improve efficiency in meeting food needs. The FAO, for example, estimates that poorly developed systems for handling, storage, packaging, transportation and marketing of agricultural products in developing countries results in post-harvest losses ranging from 15-50% (FAO, 2010). Investment in food infrastructure as well as training in food handling for those employed in the food system can reduce these losses significantly and help to ease pressure on available resources. The problem of food waste is not limited to developing countries – one study suggests that as much as 40-50% of the food that is ready for harvest in the United States is not consumed and that US households waste an average of 14% of their food purchases (University of Arizona, 2010). Kader (2005) estimates that over 30% of the fresh produce (fruit and vegetables) harvested in both developed and developing countries is lost, with the rate being highest (20%) in retail, foodservice and consumer parts of the system in developed countries, whereas in developing countries the wastage rate is highest from farmers to retail (22%). One

15 Information on the financial position of US agriculture is obtained from the online “Briefing Room” on Farm Income and Costs at the Economic Research Service, USDA (www.ers.usda.gov).

16 Computed from national accounts data from the Bureau of Economic Analysis, U.S. Department of Commerce.

estimate puts the energy embodied in wasted food in the United States as equivalent to 2% of total energy consumption – roughly the same percentage as agriculture consumes (Cuéllar and Webber, 2010).

4.2. Policies for increasing productivity in an environment of green growth

As noted earlier, technological change and improvements in productivity have played a central role in helping agriculture contribute to growth in the economy as a whole, while meeting expanding demands for food and agricultural raw materials, and improving the well-being of consumers. Research and development (R&D) and further increases in productivity will continue to play a vital role in helping agriculture to continue to achieve these outcomes, and in dealing with new challenges such as climate change. There will be a pressing need to obtain more from existing resources (particularly land and water) within a sustainable and robust food and agricultural system. A fundamental requirement for green growth in agriculture is that suitable technologies are available to farmers and that they have the knowledge and skills to use these (OECD, 2001).

A comprehensive review of trends in R&D expenditures in agriculture has been carried out under the auspices of the Consultative Group on International Agricultural Research (CGIAR). Table 5 summarises some of the estimates of total expenditure on agricultural research and development (public and private) at the beginning of the current millennium (Science Council CGIAR, 2005). Total expenditure was around USD 37 billion (2000 values, purchasing power parity basis). Public expenditure accounted for 63% of the total and the top ten countries in terms of public-sector spending (in decreasing order) were the United States, China, India, Japan, Brazil, Germany, Australia, South Korea, the United Kingdom and Canada. Over 90% of the roughly USD 14 billion in private-sector expenditure was concentrated in developed countries. Global public investment in agricultural research increased by roughly 50% in inflation-adjusted terms during the period from 1981-2000, although total expenditure in developed countries declined by roughly 4% from 1991-2000. Public research expenditures are heavily concentrated in a few countries. The United States, Japan, France and Germany accounted for two-thirds of the total in developed countries in 2000; five developing countries – China, India, Brazil, Thailand and South Africa – accounted for over half of the developing world's total.

R&D expenditures in developing countries that are expected to experience particular pressure on food supplies, such as Sub-Saharan Africa, displayed very little growth. Msangi *et al.* (2009) estimate that public sector expenditure on agricultural R&D in developing countries was equivalent to just 0.55% of agricultural GDP in 2000, compared to 2.35% in developed countries. They estimate that if developing countries are to feed their growing populations and respond to the challenges created by climate change, total research expenditures will have to be one third higher by 2050 than without climate change.

Given the numerous and increasing demands on public finances in many countries it may prove difficult for sufficient public resources to be mobilised to address productivity and environmental challenges in agriculture. As noted earlier, the private sector plays an important role in R&D in developed countries, but only a minor role in developing countries. This may be due to higher returns to the development of new technologies in developed countries, the greater protection of intellectual property rights, or to a more favourable environment for private sector investment. Whatever the cause of low private investment in developing countries, this would seem to be an area in which further analysis is needed so that the flow of investment and innovations from the private sector can be increased.

Finally, the results of research on new technologies and production methods are of little use to farmers unless they know how to apply these. Public sector support for the diffusion of new knowledge through extension has been a feature of productivity growth in agriculture around the world. For example, Rosegrant and Evanson (1992) demonstrate that expenditure on extension activities played a significant role in the growth of total factor productivity in agriculture in South Asia. In India, for example, the rate of return to investment in extension over the period 1956-87 was 52%, which compares very favourably to the 63% rate of return to research. While many of the advisory services that were previously provided through public funds are increasingly being provided by the private sector in developed countries, it seems likely that the public sector role will need to play an important role in extension in developing countries for the foreseeable future. Those countries with severely constrained public funding may find it difficult to supply needed extension services.

Table 5. Estimated annual expenditures on agricultural research and development, *circa 2000*

	Total expenditure (Billion 2000 US PPP dollars)			**Shares** (%)	
	Public	Private	Total	Share of world R&D expenditure	Public share of regional/all countries' totals
Developing countries	12.8	0.9	13.7	38	94
Developed countries	10.2	12.6	22.8	62	45
All countries	23.0	13.5	36.5	100	63

Source: Science Council of the Consultative Group on International Agricultural Research (2005), *Science for Agricultural Development: Changing Contexts, New Opportunities,* Science Council Secretariat, Rome.

Note: based on data from 28 developed countries and 139 developing countries in current local currency units, deflated to 2000 constant currency units, and converted to internationally comparable values using purchasing power parity (PPP) exchange rates.

4.3. Policies affecting factor use and agricultural production

As already noted increasing demands will be placed upon scarce factors in agriculture – particularly land and water – as a result of population and income growth. There will be a need for a policy environment that encourages the efficient use of factors of production. In addition, policies that are directed towards addressing climate change, both at the economy and sectoral levels will have an impact on meeting green growth objectives in agriculture.

One of the central issues in achieving green growth is to ensure that all the costs associated with economic activity are reflected in production and consumption decisions, *i.e.*, are internalised. In terms of market-based instruments two major approaches have been identified – one based on the use of taxes and subsidies (Pigou, 1932) and a second based on the assignment of property rights (Coase, 1960). An alternative approach is to use various non-market instruments, including regulations. Each of these approaches has advantages and disadvantages and neither is universally superior. Efficacy and efficiency depend on a range of factors including the nature of the issue to be addressed, the institutional environment, and technical limitations and constraints to be faced in the use of particular policy instruments. Some of these issues in the context of sectoral approaches for agriculture are discussed below.

4.3.1. Policies oriented towards internalising the cost of negative externalities

An important category of policies consists of those that can be used to internalise the costs of the environmental damage created by agricultural production. As noted earlier, agriculture can contribute negatively to environmental quality, for example, through nutrient discharges to water, climate change through GHG emissions, and through other effects, such as reduced biodiversity. The climate change issue, in particular, may be addressed through economy-wide policies as well as sectoral ones.

Economy-wide policies that seek to internalise the environmental costs of using fossil fuels are likely to increase the cost of fuel, as well as chemicals and other purchased inputs to agriculture. Thus a carbon tax applied to fossil fuels or a cap-and-trade scheme to internalise the costs of environmental damage will have an effect on agriculture. Internalisation will be reflected in higher input prices. Farmers will respond by trying to economise on the use of inputs. A reduction in input use would not only reduce GHG emissions, but could also have other environmental benefits, such as less contamination of water by pesticides or residues from chemical fertilisers. However, to the extent that output is also reduced this will add to pressure on prices for food and agricultural raw materials, unless offsetting changes in technology are available that can maintain the level of output.

Taxes could also be used to address emissions generated by agricultural production. Applying such taxes directly to the source of pollution is challenging since it is often difficult to monitor the amount of emissions, *e.g.,* the amount of methane produced by ruminant animals on a given farm. In theory, a tax could be applied per unit of output to reflect the contribution of production of a particular product to GHG emissions – *e.g.,* a tax per tonne of grain produced or per kg of live-weight of beef or per litre of milk. Such a tax could be levied either on estimated total crop production or on the number of animals raised. If levied on the basis of sales of products the calculation of the tax would not be straightforward – since it might fail to reflect emissions associated with unharvested crops (those not marketed but fed to livestock on farms where produced) as well as GHG emissions associated with non-marketed breeding stock or with animals that are never marketed due to death loss. GHG taxes levied on agricultural output have the disadvantage that there is no incentive for farmers to reduce the level of emissions in the production process, *e.g.,* by changing cultivation practices to reduce nitrous oxide emissions or by adjusting feeding rations for ruminants to reduce the production of methane. Indeed if a tax were applied per head of livestock there would be an incentive to maximise the sales weight of the animal in order to lower the rate of tax per kilo. The higher use of feed that this would involve could weaken the effectiveness of the tax in reducing emissions.

Another issue is that the application of taxes designed to reduce GHG emissions in agriculture could conflict with other environmental objectives. For example, there may be a desire to maintain grazing animals in order to preserve certain types of landscapes and grazing-dependent ecosystems. If a GHG tax cause farmers to reduce stocking rates or to abandon livestock farming this could have a negative impact on that ecosystem. There could also be a conflict with other types of policies, for example, the provision of subsidies under agri-environmental programmes to encourage certain types of land-use systems.

An alternative approach to taxing at the point of production would be to tax at the point of consumption. This would be relatively straightforward for a relatively homogeneous product such as liquid milk (although calculating the equivalent tax for the wide range of dairy products that can be produced from milk would pose a challenge).[17] For a non-homogeneous product such as beef the incidence of a fixed tax per kilo would be higher on lower quality and normally cheaper products. Consequently, an *ad valorem* tax would probably have to be used. Given normal variations in consumer prices the size or incidence of such a tax might actually bear little relationship to the estimated costs of the environmental damage implied by the production/consumption of the products concerned. Although the use of consumption taxes to internalise externalities is unlikely to be attractive because of technical difficulties (and resistance by consumers) some groups are trying to induce voluntary changes in consumption patterns that would reduce the demand for certain commodities such as red meat and dairy products. Clearly, the widespread adoption of such changes in consumption could have an effect equivalent to taxing the production of the products concerned, in that their production would fall with the reduction in demand.

More generally, taxes and cap and trade schemes are difficult to apply when non-point-source pollution is involved and this tends to be the case in much of agriculture. In the water quality area, for

[17] A tax on milk at the processing stage might be easier to impose, since this could be applied per unit of milk processed into dairy products. The tax would then be reflected in the prices of those products paid by consumers.

example, it can often be difficult to determine the source of the pollution of water bodies – specifically how much a particular farm contributes to the problem. Where the amount of nutrients generated can be monitored – for example, in concentrated feeding operations – it is somewhat easier to monitor the externality and to address it.

4.3.2. Policies designed to increase positive externalities and the provision of public goods

There has been an increasing emphasis in OECD countries on measures designed to stimulate positive externalities in agriculture and the provision of public goods. These include measures that are specifically targeted to the protection of environmental quality, and the modification of policy measures that have other objectives to help further this aim. The former category includes payments under a range of environmental schemes; the latter category includes the imposition of environmental conditions for the receipt of income support payments (cross-compliance).

Other things being equal, with respect to furthering environmental objectives, targeted measures are liked to be more efficient and cost effective in achieving specific environmental aims. The distribution of income support payments is unlikely to correspond to the distribution of environmental costs or benefits of agricultural production. Such payments are typically linked to current or historical production, whereas it is often the case that the volume of production from farms in areas of high environmental value is relatively low. In that case, high levels of payments to farms in relatively productive areas under cross-compliance conditions are likely to generate relatively modest environmental returns per unit of expenditure. That being said, cross-compliance is clearly preferable to price support measures that provide an income transfer to farmers without any environmental conditions. More generally, however, price and income support that is directly linked to current output is likely to intensify production, which may work against the aim of reducing the stress that farming places on the environment. Given the likelihood that public funds will be increasingly scarce in the future there is a strong argument for shifting expenditure from relatively untargeted measures for improving environmental quality to more targeted measures, such as those under environmental programmes.

Payments under environmental programmes can be used either to reduce negative externalities from agricultural activities or to increase positive externalities, and to promote the supply of public goods. Applying the logic used above with respect to internalising negative externalities the polluter-pays-principle (PPP) should dominate in this regard, *i.e.*, the externality should be taxed so that the socially optimal level of production can be generated, rather than trying to address the problem by using subsidies. However, in many countries there is considerable reluctance to impose taxes on agriculture – it is far more popular among farmers and their supporters, and often politically easier, particularly in more wealthy countries, to use subsidies to pursue environmental aims.[18] This is not to imply that the tax *versus* subsidy issue is clear cut in this area. For example, where significant capital costs are involved in the adoption of technologies to reduce pollution, public funds might be used to stimulate adoption, for example, through cost sharing. There may be a high environmental payoff in terms of reduced pollution in helping to overcome a financial barrier to the adoption of a beneficial technology. In reality many environmental programmes are composed of a mixture of measures – implicit taxes imposed by rules and regulations and subsidies – designed to reduce negative externalities, such as water pollution, and measures designed to increase positive externalities, such as an increase in wildlife populations. The advantage of such programmes is that if designed appropriately they can address environmental issues at a much finer geographical scale than other programmes, can be targeted to achieving specific environmental outcomes, and can achieve these outcomes at lower cost than through untargeted measures.

18 In fact tax concessions are often applied in agriculture. One particular example with negative environmental consequences is a tax concession applied to fuel use. The elimination of environmentally damaging subsidies is an important issue (OECD, 2003).

As with taxes, the use of subsidies to achieve environmental aims can confront problems of conflicting objectives. For example, in order to maintain a particular wildlife ecosystem (*e.g.,* one created by the grazing of hill land by ruminants) there may be a trade-off in terms in providing an incentive for the maintenance of particular production systems. Grazing animals may increase the nutrient loading in water supplies and add to GHG emissions at the same time as protecting wildlife habitat. A choice may have to be made between ecosystem preservation and other environmental objectives in this case.

4.3.3. Other policies affecting agricultural production

In addition to policies that can be directly oriented to influencing externalities in agriculture there are others that are part of the agenda for green growth. The potential negative environmental impact of price and income support policies for agriculture has been noted earlier. However, in addition to those polices input subsidies are sometimes used to try to improve the net income of farmers. In terms of their potential negative environmental impact the most notable types of subsidies are those for fertiliser, agro-chemicals and fuel, and incentives for land clearing or drainage of wetlands. From an environmental perspective there is little justification for continuing use of subsidies of this type. However, an area in which explicit or implicit input subsidisation is a more complex issue is water use. The provision of investment aids to improve irrigation systems, reducing water loss and increasing irrigation efficiency, can make a positive environmental contribution, in addition to helping “climate proof” agriculture. On the other hand, farmers are often provided with irrigation water at less than full cost. The under-pricing of water results in over-use and inefficiency. The use of appropriate pricing mechanisms for water is often highly sensitive politically, but addressing this will be a key part of helping to manage increasingly scarce water resources in the future.

Among the most significant of the other policies that need to be considered in the context of green growth are those used to promote the production and use of biofuels. As noted earlier, the production of feedstock for biofuels has been expanding in OECD and other countries in recent years. The use of agricultural crops to produce biofuels is controversial. Concerns have been raised about the implications for food prices and resource use in agriculture – particularly in countries where land that was previously used by wildlife is brought into production for biofuel feedstocks. There is also a debate on the magnitude of the net contribution of first-generation biofuels to reducing GHG emissions.

A range of policy measures are used to promote the production and use of biofuels. The principal ones are subsidies of various types and production or consumption mandates. The combinations of policy measures can be quite complex and their implications for domestic production, consumption and trade in biofuels is difficult to disentangle. A number of studies suggest that biofuels policies provide significant subsidies to agricultural producers and that they can create trade distortions (*e.g.,* Steenblik, 2007). The OECD’s own work in this area suggests that biofuel policies lead to higher world prices for crops, such as maize and oilseeds, which provide first-generation feedstocks (OECD, 2008d).

In terms of green growth, the expanded use of existing crops and the use of new agricultural crops (*e.g.,* jatropha) for biofuel production pose challenges. The demand that these will place on available land and the pressure likely to be exerted on the use of other inputs may make it difficult to improve environmental quality in agriculture if production of biofuels feedstocks is to be increased. The development of second-generation feedstocks such as woody biomass may also place additional demands on land and other natural resources and affect environmental quality, unless appropriate steps are taken. However, other potential benefits such as reduced reliance on fossil fuels would have to be considered in evaluating the future direction of biofuels policy.

4.4. Policies affecting innovation

The need for agriculture to increase its productivity and its robustness in the face of climate change will require substantial innovation in the sector. New technologies will need to be developed and adopted and production methods will have to change. If green growth is to be achieved in the sector innovation and the policies which affect this will be important.

In order the address environmental issues many manufacturing companies in OECD countries are beginning to focus on *eco-innovation*, *i.e.*, innovation that results in a reduction of the environmental impact of producing and delivering products to consumer, regardless of whether or not that effect is intended. An important feature of such innovation is that it shifts the emphasis from "end-of-pipe" pollution control to a focus on product life cycles and integrated environmental strategies and management systems (OECD, 2009b). There are many examples in food and agriculture where such an approach is important. As noted earlier, a considerable amount of "waste" can be generated in the food and agricultural system, which not only adds to pressure on the land and water resources used by the system but also represents an untapped resource. The food and agricultural system has become increasingly energy intensive. The growth in the production of "convenience" foods and changes in the presentation of foods to consumers (*e.g.,* sales of washed and packaged vegetables rather than in their relatively unprocessed state) not only increases energy usage, but also generates a higher waste stream in the form of packaging. The standards set by retailers (*e.g.*, requirements on the size and appearance of fruit and vegetables) can also add to the amount of material entering the waste stream as products that do not meet those requirements are unable to find a market. Much of the food product waste which used to be fed to livestock now ends up in landfill sites.

Green growth in agriculture and the food system will require participants in the system to examine product life cycles and for governments to evaluate what they can do to help reduce energy usage and product waste. This is already beginning to happen. For example, food retailers in some OECD countries are beginning to reduce the amount of plastic packaging they use. Various initiatives are being taken to promote the recycling of packaging materials. Many of the supply side initiatives involve the creation of networks, platforms or partnerships with participation by industry and other stakeholders. Pressure from the general public for the "greening" of the food system can be an important part of the process. Governments can assist through the use of conventional measures, such as funding research, education and demonstrations of green technologies. They can also aid the process by modifying existing regulations, *e.g.,* on product standards or the use of waste products in feeding livestock, to promote greater efficiency in the use of energy and the food and raw material production in the sector. They can also facilitate the development of new uses for "waste" in the system, *e.g.,* composting to produce soil-conditioning products or the use of waste for the production of bioenergy (providing this is done in ways that protect water quality). Demand-side measures such as green public procurement are also receiving increasing attention, as governments acknowledge that insufficiently developed markets are often the key constraint for eco-innovation. Many governments are substantial purchasers of food – for the military, for the prison population, and for food assistance programmes. Such purchases can be used to promote the greening of the agricultural sector.

There may well be substantial challenges, both technical and social, in promoting innovation and the adoption of new technologies in the food system. One particularly contentious area is the role of new technologies, including biotechnology and nanotechnology, in addressing future food needs. In 2005, public R&D expenditures in the OECD area for all types of biotechnology were USD 28.7 billion, and expenditures by the private sector in 2003 were USD 21.5 billion (OECD, 2009c). With the sequencing of the genome for major food crops close to completion, there is considerable potential for these technologies to contribute to increases in productivity in the food and agricultural system. There is a debate between those who argue that conventional plant breeding techniques are sufficient to address such challenges as increasing drought and disease resistance and those who argue that these issues can be addressed more efficiently and more rapidly by using alternative technologies. This debate is likely to continue, particularly given the level of public concern about the implications of the use of 'novel' technologies in the food system in some countries. However, the future potential of new technologies to address productivity and environmental issues is being actively evaluated in the agricultural research community (CGIAR, 2005). As noted earlier, a range of policy issues are involved, including the allocation and use of public funds for research, the legal framework for the protection of intellectual property, and the nature of regulations governing food safety. While it is not possible to reach definitive conclusions on how these policies will affect future innovation in the sector or indeed what the future direction of policies in these areas should be, it is clear that the implications for the ability of the sector to meet future food demands while achieving green growth will have to be evaluated.

4.4. Policies affecting the functioning of markets

Globalisation and the increasing integration of domestic markets has played a major role in stimulating world economic growth in recent years, although the risks associated with such integration have also been demonstrated by the global financial crisis that began to unfold in 2007 and whose effects continue to be felt today. The crisis has stimulated considerable debate about the future implications for policy and, in particular, the role of markets *versus* regulation in economic affairs (Blandford, 2010). As has been argued earlier, achieving green growth in agriculture is likely to require a combination of largely market-based instruments and regulation. A central issue will be the appropriate balance between the two. The primary focus of policy choice needs to be on the effectiveness and efficiency of alternatives, although other important issues, particularly distributional implications need to be taken into account.

There is likely to be considerable support for measures that will improve the efficiency of markets in achieving policy objectives, such as those embodied in a green growth strategy. However, there are also measures that can be taken that impede the efficient functioning of markets and are likely to either impair the achievement of green growth objectives or generate other undesirable outcomes. For example, growth in agricultural trade and the closer integration of national agricultural markets has been a significant feature of global economic growth in recent years. The annual expansion of world trade in agricultural products has typically been more rapid than that for world agricultural production or GDP. For the period 2000-08 world exports of agricultural products grew at an average annual rate of 5%, compared to a 2.5% rate for agricultural production and 3% for GDP (WTO, 2009). In the future, international trade will continue to play an important role in meeting world food needs and in buffering the world food economy against shocks due to climatic events. However, trade restrictions can contribute to "thinness" in international markets and accentuate international price volatility (OECD, 2008b). Volatility can be further accentuated by emergency measures taken to restrict exports when changes in the international supply/demand balance threaten to cause increases in domestic prices.

4.5. Policies for international collaboration

Much of the policy focus on achieving green growth will inevitably be domestic in nature. Each country will need to evaluate what will contribute to green growth in its agricultural sector and how the domestic policy environment can contribute to achieving that aim. However, there is also an important role for international collaboration. As already noted, unilateral actions in the face of stresses and strains in the food system, such as those generated by extreme weather events, can intensify problems in the food system of other countries. There is a need to avoid such unilateral actions if the stability of the global food system is to be ensured in the future. Similarly, multilateral actions to reduce the use of harmful subsidies and incentives that promote negative environmental effects and international coordination in the use of measures to promote positive environmental outcomes could play an important role in achieving green growth objectives. Since much of the future emphasis in meeting food needs will be on increasing productivity in developing countries, it is particularly important that they do not adopt inappropriate policies to subsidise the use of inputs or output that are inconsistent with achieving green growth objectives globally.

Beyond this, however, there is a role for proactive international action in several areas to achieve green growth objectives. The sharing of the results of R&D and new knowledge that contributes to the greening of agriculture is important. There is considerable potential for taking advantage of spillovers at the international level from the development of new production methods in agriculture (CGIAR, 2005). The use of international aid to facilitate the adoption of green growth technologies in developing countries could be an option. International coordination in the face of weather-induced disasters affecting agriculture, which is already a feature of the activities of several international agencies, will also become more important. Although recent experience in the area of climate change policy suggests that it will not be easy to reconcile the sometimes competing needs and objectives of countries, an on-going international dialogue will be needed if successful approaches to achieving green growth in world agriculture and the global economy as a whole are to be found.

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