Identifying Agricultural Research and Development Investment Opportunities in Sub-Sahara Africa; A Global, Economy-Wide Analysis

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Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006

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August 2006

Abstract

Sub-Saharan Africa (SSA) is the most important development challenge of the 21st century. Poverty is higher in most African countries than elsewhere in the developing world. According to the recently published Report of the Commission for Africa, economic growth in Africa is necessary for substantially reducing poverty. Among three proposed policy options, the Commission recommends that African countries invest significantly in agriculture. But policy makers in the region face a dilemma: which sub-sector within agriculture will yield the highest return for a given budget? This paper uses a computable general equilibrium model to simulate productivity gains in sub-Sahara African agriculture subject to trade-offs between gains in crops and gains in livestock. The simulated results suggest three conclusions. First, most of the sub-Sahara Africa economies gain more from research and development (R&D) investment in crops than from R&D investment in livestock but this conclusion is not true everywhere. The SACU (South African Customs Union) economies and Madagascar benefit from a sharing of R&D investment between crops and livestock. Second, when R&D is focused on food crops, a sharing of investment funds between crops and livestock is beneficial to other economies too. Third, in economies where a sharing of R&D investment between crops and livestock is beneficial (e.g., Botswana), general economic growth boosts the benefits from R&D investment in livestock.

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The views expressed in this paper are those of the authors and do not necessarily represent those of the World Bank, the U.S. ITC, or any of their officials.

Identifying agricultural research and development investment opportunities in sub-Sahara Africa: a global, economy-wide analysis

Introduction

Sub-Saharan Africa (SSA) is the most important development challenge of the 21st century. Poverty is higher in most African countries than elsewhere in the developing world: about 40% of the population of SSA lives on less than one U.S. dollar a day; those most vulnerable to poverty live in rural areas and large households that are often headed by women; education is low for these most vulnerable groups, and they are also most likely to live in countries with real growth rates of less than 5% (World Bank 2000; Sachs, 2005).

According to the recently published Report of the Commission for Africa (Commission for Africa, 2005), economic growth in Africa is necessary for substantial reductions in poverty. Among three proposed policy options the Commission for Africa recommends that African countries invest significantly in agriculture. The Commission made this recommendation because agriculture continues to remain a central part of African economies. It contributes at least 40 percent of exports, 30 percent of GDP, up to 30 percent of foreign exchange earnings, and 70 to 80 percent of employment. Therefore accelerating growth in agriculture will be critical to sustained growth and poverty reduction (Hazell, 2005). Also since women play a major role in African agriculture investing in agriculture will help combat the inequality women face in the region.

But despite the fact that agricultural led growth played an important role in the economic transformation of many Asian and Latin American countries and helped slash poverty, with few exceptions, the strategy has not worked in SSA. As a result many SSA countries still face national food constraints. The lessons from Asia and elsewhere are clear. There is need for more research and development (R&D) investment in agriculture. But policy makers in the region face a dilemma: which sub sector within the agricultural sector will yield the highest return for a given budget? Since crops and livestock together constitute the largest share of the agricultural GDPs, it is useful to ask the following questions: for a given amount of funds will R&D investment in all crops bring the highest returns to the economy or will it be R&D investment in livestock? Since achieving food security is a major policy challenge for many African countries, and that most R&D investment does not go food crops, we further ask if R&D investment in food staples only will yield a higher return than comparable R&D investment in livestock. Also because the decision to invest in a particular sub sector may dependent on the comparative advantage of a country in that sector we single out the case of Botswana, a country where livestock is a more important sub sector than in any other in SSA and we ask the same question. Finally we asked how resource allocation may change in the presence of economic growth. This question is legitimate because economic theory suggests that food preferences shift to high value commodities such as livestock when income rises. Again to illustrate this case we focus on Botswana where economic growth rates in resent years have been in the order of 5-7 percent per year (AfdB/OECD, 2004)

Addressing these policy questions is opportune for several reasons. First over the last 30 years African people have on average seen virtually no increase in their incomes and policy makers, development and donor agencies are looking for ways to increase growth in Africa (e.g. the recent report of the Commission for Africa, 2005). World development indicators show that in 2002 the total production (gross domestic product (GDP) of SSA amounted to only US$319 billion, which was less than one percent of the world's total production (World Bank 2003). The region has the lowest per capita income in the world ($315), a level that has changed little and in some countries has actually declined. Annual economic growth in Africa fell from 4.9 percent in the 1960s to 1.9 percent in the 1990s (Commission for Africa, 2005). Over two hundred million people are chronically hungry (Rosegrant *et al.*, 2004; AAPP, 2005). Among them, the most vulnerable are children. As can be seen in Figure 1, Africa will not only miss its MDG targets in 2015 but the nutritional status of its children is worsening instead of improving as in other regions. Under- nutrition, especially among children, is the most world underlying cause of illness and death (Masters, 2005).

Second, while SSA is blessed with abundant natural resources on a per capita basis, yields are so low that that there are plenty of opportunities to raise them through technological change. But funding for agricultural research and development in the region has been declining (Masters, 2005). Consequently while agricultural output is growing, productivity is not (World bank, 2002). Food production per capita has declined 17% in SSA from an already low level since 1970, the most of any major region of the world (Figure 2). Cereal yields have remained stagnant since the mid-1970s, while yields have doubled in other regions of the developing world, and now average only one third of yields in other developing regions (Figure 3). Yields of other food crops and livestock have also declined since the 1970's (World Bank 2000, 2002). Beef yields have decreased by 10% since 1970 (Figure 4). These low productivity levels have eroded the competitiveness of African agriculture in the world market; as a result most countries in the region have become net importers of food commodities.

Third, through AU/NEPAD and the Regional Economic Communities (RECs), African Union heads of state and ministers have expressed their recognition of the crucial role of agriculture. In Abuja in October 2001, Africa's leaders emphasized the critical importance of agriculture as the cornerstone of the continent's sustained growth and poverty reduction. They have outlined a broad strategy to achieve their "*Millennium Development Objective*" based on: (i) improving governance and preventing conflict; (ii) massively investing in people and in infrastructure; and (iii) increasing the competitiveness and diversification of the African economies, in particular of African agriculture.

This paper's contribution to the literature is to use a computable general equilibrium model to simulate productivity gains in sub Sahara African agriculture subject to trade-offs between gains in crops and gains in livestock. The first part of this paper provides an overview of the literature that has examined the effects of productivity gains in African agriculture. The second part of the paper specifies an applied general equilibrium (AGE) model of the global economy depicting 19 economies and 26 industries. The model is used to simulate changes in agricultural productivity in sub-Sahara Africa. Lacking data on trade-offs between productivity gains in crops and productivity gains in livestock, we develop a framework on which we base our simulations.

Our results suggest three conclusions. First, most of the sub-Sahara Africa economies gain more from R&D investment in crops than from R&D investment in livestock but this conclusion is not true everywhere. The economies of South Africa, Botswana, the Rest of SACU[1] (South African Customs Union), and Madagascar benefit from a sharing of R&D investment between crops and livestock. Second, when R&D is focused on food crops, a sharing of R&D funds between crops and livestock is beneficial to other economies too. Third, in economies where a sharing of R&D funds between crops and livestock is beneficial (e.g., Botswana), general economic growth increases the benefits from R&D in livestock.

Literature Review

Several studies have shown the important contribution of R&D investment agricultural research to overall productivity growth, increasing crop yields and production and the high rate of return to R&D investment in research (Evenson and Rosegrant, 1993). Impact studies (ex ante and ex post) are one way of providing convincing evidence that agricultural research has been or will a good investment. Although there have been a large number of studies that have been completed globally, the number of studies carried out in SSA is very small compared to other regions.

The Rate of return (ROR) is the commonly used approach to assess R&D investment in agricultural research. The ROR summarizes the benefits, costs and time frame of the research or R&D investment activity in a single measure. The RoR approach permits comparisons of returns to investments in research to those obtained from alternative investments. The RoR is easily compared to interest rates or other measures of the costs of obtaining funds, and in many cases it is also comparable across

[1] Rest of SACU (South African Customs Union) consists of Lesotho, Namibia, and Swaziland.

projects (Oehmke, and Crawford, 1993; Anadajayaseram *et al.*, 1996). Generally RoR assessments for SSA find positive returns to investment in agricultural research and development. A review of studies by Oehmke and Crawford (1993) shows positive returns ranging from 3 percent for cowpea research in Cameroon, to 135 percent for Maize in Mali. Masters et al (1998) reviewed 32 estimates of RoR in Africa. They find that out of the 32 studies, only 8 report rates of returns below 20 percent. Their work confirmed that rates of returns to research in SSA are similar to those found elsewhere showing high payoffs for a wide range of programs. They also find that payoffs are lower in lower-potential areas underlying the ideas of having different strategies for different development domains (Ehui and Pender, 2005).

In terms of commodity focus, most of the returns to R&D investment studies focused almost exclusively on crops limiting comparisons with livestock. But this is not surprising since globally, overwhelmingly evaluations have focused on research in crops (Alston *et al.*, 2000). This is because livestock research is generally more difficult than research on crops. In crop research, much of the benefit to date has been generated through varietal development. Livestock research, on the other hand, is slower, more costly, and more difficult than crop research. The nature of these complexities is well summarized by Jarvis (1986): "Individual animals are dramatically more expensive than individual seeds or plants. For animals, several years elapse between conception and maturity, and substantial time is required before the impact of new technologies can be evaluated. Experimental control is difficult because animals move about and animal personality affects the results. Interactions with management variables are also complex. Livestock research is essential, but technological advances are piecemeal and slow;

governments must be prepared to provide funds over lengthy periods without expecting quick, dramatic breakthroughs."

Analyzing the impact of animal agriculture development project in the past, Winrock International (1992) argues that range-livestock projects have been the most disappointing. Range-livestock systems that were designed to replace traditional systems with new production forms and improved technology like reseeding and improved grazing systems failed completely. In crop-livestock systems where more options are available, projects have performed better. In an assessment conducted by the World Bank of 125 animal agriculture projects implemented in Sub-Saharan Africa from 1967 to 1983, it was found that crop-livestock projects and other livestock components projects were more successful than pure livestock projects.

Similar conclusions were reached by a USAID evaluation of 104 livestock-related projects implemented between 1954 and 1981 (Winrock International, 1992). The few success stories in smallholder dairy production in East Africa and animal traction in West Africa are concentrated in the crop-livestock systems. In East Africa, smallholder dairy development, which started about 1955, has been one of the few successful stories. Returns from milk and forage production have been consistently higher than the returns to crops like beans and maize, a key factor explaining this success (Winrock International, 1992). In semi-arid zones of West Africa, where the introduction of animal traction began in the 1940s, the number of oxen was almost doubled between 1979 and 1981-1983. This was made possible by the existence of profitable cash crops (cotton and groundnuts) and effective input supply, credit and extension services for cotton production, especially in the francophone area (Winrock International, 1992). A third success story is the introduction of animal health technology in many regions and production systems reducing the threats of diseases such as rinderpest and contagious bovine pleuropneumonia (Winrock International, 1992).

Although the RoR approach used in most studies yields significant insights into assessing the impact of research in agriculture, like any partial equilibrium approach, it also presents some limitations. It assumes that prices and production of all other commodities are fixed. For example the ROR approach would assume that changes in the cost of production of livestock would not alter prices of grains. In contrast the applied general equilibrium (AGE) framework allows for endogenous movements in regional prices and quantities in response to technical change. Another limitation of partial equilibrium approaches such as the ROR approach is its frequent lack of economic structure. Often, they are driven by reduced form supply and demand elasticities which cannot easily identify specificities in consumer preferences, technology or factor mobility. This makes it difficult to interpret the results of these models and leaves open the possibility of theoretical inconsistencies (Hertel, 1990).

Data and Methodology

It has now become standard practice to analyze the impacts of international economic developments within global trade models that rely on AGE methodologies, see for example Hertel, *et al*., 1996; McDougal and Tyers, 1997, Tsigas, *et al.,* 2002; and Rae and Strutt, 2003. Several of these AGE studies are based on the GTAP (Global Trade Analysis Project) framework (Hertel, 1997). We apply the GTAP framework to analyze the impact of agricultural R&D investment in sub-Sahara Africa.

The GTAP framework

The GTAP model is based on assumptions that are common in the literature: perfect competition, constant returns to scale, and no change in the economy-wide employment of resources. Each regional economy consists of several economic agents: on the final demand side of the model, a utility-maximizing household purchases commodities (for private and government use) and it saves part of its income, which consists of returns to primary factors and net tax collections. On the production side of the model, cost-minimizing producers employ primary factor services and intermediate inputs to supply commodities. In the model, intermediate (and final demand) users of commodities are assumed to differentiate a commodity by its region of origin (i.e., the *Armington* specification is applied). The GTAP model is solved using the GEMPACK suite of software (Harrison and Pearson, 1994).

A global and economy-wide approach is most appropriate for this analysis. When certain agricultural industries gain in productivity, other agricultural sectors would be affected too not only through price changes in intermediate inputs (e.g., cheaper feed grains), but also through price changes in primary factors (e.g., land and labor), which would affect incomes, and consumption of food items. The global markets aspect of the approach is important too. The extent and conditions of international trade would determine the benefits accruing to a particular economy.

Our analysis is based on aggregated data and parameters derived from the current GTAP database, version 6.0 (Dimaranan and McDougall, 2005). The base year is 2001. Our data has five primary factors: land, unskilled labor, skilled labor, natural resources, and capital. The industry and region specification of our data is show in Table 1. There are 26 industries and 19 regions. We focus our analysis on the 12 Sub-Sahara Africa countries and regions that are identified in GTAP, and on 8 crop and 4 livestock sectors.

Specification of simulations

Our objective is to identify R&D investment opportunities in agriculture with the highest rate of return in sub-Sahara Africa. Agricultural R&D investment expenditures are assumed to lead to increases in the productivity of crop and livestock activities, which then lead to economy-wide benefits in sub-Sahara Africa. In particular, we model productivity gains in crops and livestock as Hicks-neutral technological change.[2] We take the simulated economy-wide welfare impact as an indicator of returns to agricultural R&D investment.

Our approach is, first, to establish the tradeoffs between productivity gains in crops and productivity gains in livestock, for a given amount of R&D investment funds. That is we assume that if a research budget is divided equally between crops and livestock, the resulting productivity gains in crops (livestock) would be lower than if the research budget were devoted to solely crops (livestock).

We then perform three sets of simulation. First, we examine the trade-offs between research in all crops and in all livestock activities. Second, we narrow our definition of crops and we focus on the food crops in our model: rice; wheat; other cereal grains; vegetables, fruits, and nuts; and oil seeds. That is we do not consider productivity

[2] In a production function framework, technological change is Hicks-neutral when it does not affect the optimal choice of inputs. We implement Hicks-neutral productivity changes by shocking the exogenous GTAP variables $aoall_{ir}$, $i \in PROD\_COMM$ and $r \in REG$.

changes in sugar crops, plant fiber crops and other crops.[3] Third, we select Botswana, a country where livestock is a more important sector than in other sub-Sahara Africa, to study the food crops-livestock trade-offs. Agriculture in Botswana is dominated by livestock rearing, meat and dairy, production, estimate at 80 percent of the sector's value added while food crops (maize, sorghum, millet and beans) account for the remaining 20 percent. For Botswana, we also examine the consequences of economic growth on the benefits from research in agriculture. With economic growth rates averaging 5-7 percent per year in recent years, Botswana is one of Africa's success stories of sustained economic growth anchored on good governance, political stability and prudent macroeconomic management (AfDB/OECD, 2004).

Lacking data to empirically establish those trade-offs in crops-livestock productivity gains, we consider an R&D investment budget that would lead to a 10 percent productivity gain in crops, if all funds were devoted to crops. We then ask the question: how much would livestock productivity increase if the whole budget were devoted to R&D investment in livestock? The literature suggests that, for the same amount of funds, productivity gains in livestock are more difficult to be achieved than productivity gains in crops (Winrock International, 1992; Nin *et al*, 2005; Jarvis, 1986). That is, if certain research expenditures produce a 10-percent productivity gain in crops, the same expenditure would produce a 6- or 4-percent productivity gain in livestock. Since we do not have data to illuminate the trade-off, we also consider a 10- and a 2-percent productivity gain in livestock, when the whole research budget is devoted to livestock research.

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[3] Other crops include tobacco, cocoa, coffee, tea, spices, cut flowers, and seeds.

Finally, we establish the intermediate points in the crops-livestock productivity gains trade-off by simply graphing the frontiers shown in Figure 5. We simulate different allocations in research budgets by choosing different points on the frontiers in Figure 5. For example, assuming frontier A in Figure 5, if a research budget is divided equally between crops and livestock, we simulate a 5 percent productivity gain in crops and a 7.375 percent productivity gain in livestock.[4] But if we assume frontier C in Figure 5, and an equal allocation of research funds between crops and livestock, we would simulate a 5 percent productivity gain in crops and a 2.875 percent productivity gain in livestock. We simulate 11 budget allocations for each one of the four frontiers graphed in Figure 5. Frontier E is used in the Botswana simulations.

Findings

Tables 2-9 summarize the implications of three sets of simulations. First, we examine the trade-offs between research in all crops and in all livestock activities. Second, we narrow our definition of crops and we focus on the food crops in our model. Third, we select Botswana, a country where livestock is a more important sector than in other sub-Sahara Africa, to study the food crops-livestock trade-offs. For Botswana, we also examine the consequences of economic growth on the benefits from research in agriculture.

Most of the tables show the estimates of welfare effects. Welfare effects in the GTAP model are based on a utility function and they provide a summary of the effects of factor returns and commodity prices.

[4] The sector "Crops" refers to the eight crop sectors in Table 1, and the sector "Livestock" refers to the four livestock sectors in Table 1.

Crops vs. livestock in sub-Sahara Africa

We perform four series of simulations for each economy in our model. Each column in Tables 2-5 represents a different allocation of R&D investment funds between crops and livestock, and thus a different set of productivity gains for crops and livestock. Column "a1" in Table 1 represents the case where all research funds are devoted to crops and as a result productivity in crops increases by 10 percent in all sub-Sahara Africa regions. Column "a2" in Table 1 represents the case where 90 percent of the research budget is devoted to crops and the rest is devoted to livestock research. As a result of the 90-10 percent allocation of funds, productivity in crops increases by 9 percent in all sub-Sahara Africa regions; productivity in livestock increases by 1.9 percent in all sub-Sahara Africa regions.

The simulated welfare effects suggest that for sub-Sahara Africa, as a whole, research in crops would generate higher welfare benefits than sharing of research funds between crops and livestock. Even under the most favorable conditions for livestock, sub-Sahara Africa gains more from research in crops than from research in livestock (see Table 2). The largest welfare gains for the region as a whole occur in simulation "a1"at the rate of $4,293 million per year. For South Africa and Botswana, however, welfare benefits peak at simulation "a6" where crops productivity has been assumed to increase by 5 percent and livestock productivity has been assumed to increase by 7.4 percent. The Rest of SACU (simulation "a6") and Madagascar (simulation "a4") are also benefiting by a sharing of R&D funds between crops and livestock. Botswana and South Africa gain the most by a sharing of R&D investment funds between crops and livestock in Table 3 too (the 10 and 6 percent productivity scenarios for crops and livestock). In Tables 4 and 5, however, the other sub-Sahara Africa economies gain more from research in crops than from research in livestock. This result confirms conclusions reached in other research (IFPRI) and it is mainly driven by the relatively small GDP share of livestock in the sub-Sahara Africa economies.

Table 6 shows the effects of R&D investment in sub-Sahara Africa (under frontier B in Figure 5) on the output of the cattle sector. In some economies (i.e., Botswana, South Africa. Rest of SACU, Zimbabwe, and Rest of SADC[5](Southern Africa Development Community)) cattle output expands by more when more research funds are allocated to livestock research. In other economies, however, cattle output expands by less when more research funds are allocated to livestock research (e.g., Malawi, Tanzania, Zambia, and Uganda). It appears that for the latter group of economies there are strong linkages between crops and livestock. It is expected that as crops gain in productivity, livestock would expand due to lower prices for feedstuff and higher land availability. In this case, however, the indirect benefits for livestock from productivity gains in crops outweigh the direct benefits from productivity gains in livestock itself.

Food crops vs. livestock in sub-Sahara Africa

Table 7 shows the welfare effects of R&D investment in sub-Sahara Africa food crops and livestock under frontier A in Figure 5. A significant share of crop production is assumed not to be the beneficiary of R&D investment in these simulations. Thus, as expected, the sub-Sahara Africa welfare effects in Table 7 are smaller than the welfare

[5] Rest of SADC (Southern Africa Development Community) consists of Angola, the Democratic Republic of Congo, Mauritius, and Seychelles.

effects in Table 2, for the simulations where crops gain in productivity (that is simulations "a11" and "e11" produce the same welfare impacts). As in Table 2, welfare gains for Botswana, South Africa, the Rest of SACU, and Madagascar peak at research budget allocations that involve a sharing of funds between food crops and livestock. In addition to those four regions, three more countries/regions benefit by a sharing funds between food crops and livestock: Zimbabwe, Rest of SADC, and Rest of sub-Sahara Africa. The countries that continue benefiting by focusing research on crops are Malawi, Mozambique, Tanzania, Zambia, and Uganda.

Botswana

In the last two sets of simulations we focus on Botswana and we simulate food crops-livestock productivity changes from frontier E in Figure 5. Agriculture contributes only around 2.4 percent of Botswana's GDP, but cattle production accounts for about 80 percent of agricultural output.

Frontier E in Figure 5 assumes that research in livestock can produce productivity gains (15 percent) that are larger than when research is devoted to food crops (10 percent).

Table 8 shows the welfare effects of R&D investment in Botswana's food crops and livestock under frontier E in Figure 5. As expected (from the results in Table 7), Botswana benefits from sharing research expenditures between food crops and livestock. Welfare gains peak at simulation "f9", which involves a higher percentage of funds devoted to livestock than that implied by simulation "e7" in Table 7.

The Botswana economy has achieved relatively high growth rates during the recent past. Botswana's GDP grew by 6-6.5 percent during 1999-2000; growth slowed down in 2001 (4.7 percent); but growth accelerated during 2002-03 (6 and 7.6 percent, respectively) (CIA, 2004).

To examine the consequences of economy-wide growth on the benefits of agricultural research in Botswana, we simulate 7.5 percent growth in primary factors coupled with research in food crops and livestock (frontier E in Figure 5). Table 9 shows the welfare effects of economic growth coupled with research in Botswana's food crops and livestock. Table 9 suggests that welfare gains peak at simulation "g9".

A comparison of the welfare effects in Table 9 with those in Table 8 suggests that economic growth in Botswana makes research in livestock more valuable. This conclusion is based on the decomposition of welfare, into three components, which is shown in Figure 6. The first component is the welfare benefit due to 7.5 percent growth in primary factors which remains the same (i.e., USD 323.783 million) under all research budget allocations. The second component is the welfare benefit from agricultural research in the absence of economy-wide growth (as shown in Table 8). In Figure 6 the second component peaks at simulation no. 9. The third component is the impact of economy-wide growth on welfare benefits from research. The third component increases as more funds are allocated to livestock R&D investment (e.g. research development) and it peaks at simulation 9.

Policy implications

This study confirms other studies (e.g. Hazell, 2005; Diao, 2004) that the greatest potential for most African farmers still lies in domestic and regional markets for food staples principally crops. Staple crops represent about 70 percent of agricultural output or about $50 billion per year (Hazell, 2005). Investing in staple food crops will translate into market transactions in addition to providing for on farm-consumption. But a discernment needs to made for countries such as Botswana, South Africa, Madagascar where livestock constitute a higher proportion of the agricultural output. In such countries the economy benefits from shared R&D investments in both crops and livestock. The case of Botswana illustrates that economic growth makes livestock research more valuable. This is because with income growth consumption patterns change towards high valued products such as livestock.

The policy implication of these finding are: policy makers should focus their attention on the smallholder producers who constitute the majority of traditional crop producers. But for the traditional crop sub sector to take off will require that several actions are taken. Those in the position to help improve the lives of the African people should help to (see Ehui, et al. 2002):

Improve R&D investment in agricultural research. Currently, many donors and stakeholders are concerned that several decades of agricultural research have not had the desired impact on agricultural productivity, poverty and food security, as the projects they have funded had aimed to achieve. Thus, it is important to revisit the research and development agenda and increase investments in agricultural (especially food staples)

R&D that leads to improved technologies to: increase poor farmers' production; provide poor farmers and landless people with greater employment opportunities and higher wages; benefit a wide range of poor people through growth in both rural and urban economies; lower food prices for all consumers; increase physical and economic access to foods that are high in nutrients and crucial for the well-being of the poor, especially women and children; and reduce the vulnerability of the poor to shocks via asset accumulation (Hazell and Haddad 2001). It is also important that agricultural research should not choose technologies for poor farmers, but rather make available a menu of technology options from which they can choose to fit their own needs and resources.

Improve markets, infrastructure and institutions. Fair, proper-functioning markets and access to both inputs and food at reasonable prices are needed for poor farmers to fully capture the benefits from improved human resources and access to improved technologies. Improved and timely access to credit, productive inputs (especially inorganic fertilizers) and extension, especially to women farmers are crucial. Women's potential contribution to agricultural production have not been adequately nurtured, although evidence shows that if women had access to the same amount of capital and productive inputs as men, the value of their farm output would increase by up to 24% (see Quisumbing *et al.*, 1998 for review of the evidence). Policies (taxes and subsidies) that create distortions in capital markets to favor large enterprises and limit capital to small-scale farmers must be removed. Increasing investments in rural access roads and irrigation are also critical, as these are among the top investments driving agricultural growth in the 2020 projections. Whether to expand or rehabilitate existing infrastructure will have to be evaluated on a case-by-case basis by individual governments. However, the investments should not be restricted to high agricultural potential areas, as Fan et al (2000) have shown that less-favored areas can give the most growth for an additional unit of investment, and investment in less favored areas also has more impact on poverty reduction.

Improve natural resources management: As the opportunities for expanding agricultural area are limited in may cases, ecologically and economically, most of the increases in agricultural growth will have to come from increase in crop and livestock yields. Thus, ensuring sustainable increased yields through improved technologies for management of water and land and effective property rights to natural resources is important. More agricultural research leading to improved technologies and extension to help poor farmers solve problems of soil erosion and nutrient depletion is necessary, in addition to providing better access to credit and fertilizer. Cheap alternative sources of fuel and construction material to reduce deforestation, policies that increase the profitability of maintaining forests (Kaimowitz *et al.,* 1998), and policies to mitigate the negative effects of global warning and climatic change are also needed.

Improve human resource. Good nutrition, health and education are important indicators of well-being, which is necessary for active participation in a nation's development process. Thus, policies to improve health and nutrition must deal with poverty-relating diseases such as HIV/AIDS[6], tuberculosis and malaria, and must provide access to safe drinking water and food. Health, water and nutrition education programs to generate public awareness are also crucial. Increasing school enrolment especially for

[6] AIDS have had a devastating impact on agricultural production in SSA, through its negative impact on life expectancy. In 2000, about 70% of the people estimated to have AIDS worldwide were found in SSA, with 16 countries having more than 10% of their adult population affected (FAO 2001).

women is very important, as improving status and education of women have been shown to improve household nutrition and food security.

Improve macroeconomic policies: The effectiveness of the above policy actions will depend on sound macroeconomic polices, especially those related to exchange rates and trade. Correcting overvalued exchange rates and removing policies that discriminate against export will be important. Good governance and integrating the civil society into government will be needed to eliminate conflict, which severely impact household and national food security. Several African countries have experienced significant civil conflict over the past decade, and millions have been killed, maimed, or displaced and deprived of their livelihoods. Conflicts present enormous challenge to rural development, as it takes land out of production, reduces labor force and reduces the incentives to invest in farms and other businesses. It also consumes scarce national resources that could otherwise be spent on health care, education, infrastructure, research and other investments for development. Although the private sector and market systems should be allowed to operate without distortions, governments should endeavor to provide an enabling environment through decentralization and providing or improving public goods needed by the poor, including an effective and fair legal system.

Mitigate the impact of globalization. The effects (both negative and positive effects on poverty and food security) of globalization—international trade liberalization, opening up of economies and free flow of capital, labor, information and technology—are inevitable. Thus, SSA needs to identify those potential effects and adopt policies that will minimize the negative effects and maximize the positive effects of globalization on the rural poor. Historically both developed and developing countries, including SSA, have maintained protective barriers to agricultural and agro-industrial trade. This has had negative consequence for agricultural development in SSA by constraining opportunities for raising incomes as well as alleviating poverty. However, while in recent years SSA has reduced the barriers to agricultural trade considerably, developed countries' agricultural policy reforms and the last round of the trade negotiations initiated only limited actions to reduce or eliminate barriers to agricultural and agro-industrial trade. For example, Organization for Economic Cooperation and Development (OECD) farmers remain protected by subsidies that are in sum equivalent to Africa's total GDP. This is making it difficult for SSA farmers to compete in their markets, as those adverse trade policies are accelerating the declining trend in world agricultural prices. In addition to the subsidies of the OECD countries, there are non-tariff barriers; and environmental standards are ready to be imposed as another set of non-tariff barriers.

OECD countries need to take a big picture view of trade in which developing countries are potentially huge markets for their industrial and service products. However, that requires that the millions of rural poor people are raised out of poverty and acquire sustained purchasing power. Barriers to agricultural trade in commodities in which SSA has a comparative advantage are protecting relatively small agricultural sectors in OECD countries at the expense of markets for their own major industries. While we agree that domestic policy reforms in SSA need to continue, we believe that the focus has to be on removing the constraints on agricultural trade imposed by developed countries. Specifically, we argue that export subsidies in the developed countries should be outlawed and domestic producer subsidies removed. Access to developed countries markets under tariff quotas must be increased and tariff escalation on processed agricultural products removed. Trade is a 'two-way street' and it is very much in the self-interest of the developed countries to promote fair and freer trade in agriculture.

Protectionism in SSA is not the solution either. SSA countries should continue to reform their domestic policies to be competitive in global markets. To achieve this, as discussed above, they need to eliminate internal biases against agriculture, increase investment in rural infrastructure, health, education and human capital in general. They would also need to promote improved agricultural technology for the smallholder farmers; improve management of land and water resources; improve tenure security; facilitate the vertical integration of small farmers with processors; and improve the organizational abilities of the small farmers.

Summary and conclusions

Our results suggest three conclusions. First, most of the sub-Sahara Africa economies gain more from R&D investment in crops than from R&D investment in livestock but this conclusion is not true everywhere**.** The economies of South Africa, Botswana, the Rest of SACU, and Madagascar benefit from a sharing of research between crops and livestock. Second, when research is focused on food crops, a sharing of research funds between crops and livestock is beneficial to other economies too. Third, in economies where a sharing of research between crops and livestock is beneficial (e.g., Botswana), general economic growth increases the benefits from research in livestock.

Our results do not imply that investing in livestock and other non traditional high value commodities is not important. In many successfully transforming economies in

SSA, domestic and foreign demand for these products is growing rapidly providing ready market outlets for increased domestic production for these high value commodities (Hazell, 2005). While there are opportunities for improving livestock and other non traditional exports through better quality and niche markets, findings in this paper show that the greatest market potential for most African farmers still lies in domestic and regional markets for food staple crops. The policy actions that can help boost agricultural production especially crops include:

- increasing R&D investments in agricultural research that leads to improved technologies to increase crop and livestock production, provide greater employment opportunities and higher wages, lower food prices, and reduce the vulnerability of the poor to shocks via asset accumulation;

- improving markets, infrastructure and institutions so that poor farmers can fully capture the benefits from improved human resources and access to improved technologies;

- improving human resource in the provision of health and education, especially for women;

- adopting policies that will ensure sustainability of increased yields through improved technologies for management of water and land and effective property rights to natural resources; and

- removing policy distortions that favor large-scale enterprises at the expense of smallholder producers.

- Since globalization—international trade liberalization, opening up of economies and free flow of capital, labor, information, and technology—is inevitable, SSA needs to continue position itself and adopt policies that will minimize the negative effects and maximize the positive effects of globalization on the rural poor and food security. The domestic policies mentioned above will help SSA countries respond better to the effect of globalization. But the international community should help eliminate the constraints on agricultural trade imposed by the developed countries. Export subsidies should be removed and domestic producer subsidies reduced. Access to developed countries markets under tariff rate quotas must be increased and tariff escalation on processed agricultural products removed.

This paper has two limitations. First the trade-offs between crops and livestock were ascertained on an ad hoc basis. We plan to extend our work by providing empirical foundations to our assumptions regarding trade-offs in productivity gains between crops and livestock. The second limitation is that the rest of SSA region is at present not sufficiently disaggregated to permit more of the type country level analysis of the type we did for Botswana. There are certainly other countries in the Rest of SSA where livestock output constitutes a large share of the agricultural GDP and where possibly sharing of R&D investment fund funds between crop and livestock will yield larger benefit than R&D investment in food crops alone. As the GTAP database expands to include more African countries, more country-level analysis can be done.

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Table 1. Industry and region specification

Number	Industry	Number	Region
	Crops		**Sub Saharan Africa**
1	Paddy rice	1	Botswana
2	Wheat	2	South Africa
3	Cereal grains nec	3	Rest of SACU
4	Vegetables, fruit, nuts	4	Malawi
5	Oil seeds	5	Mozambique
6	Sugar cane, sugar beet	6	Tanzania
7	Plant-based fibers	7	Zambia
8	Crops nec	8	Zimbabwe
		9	Rest of SADC
	Livestock	10	Madagascar
9	Bovine cattle, sheep and goats, horses	11	Uganda
10	Animal products nec	12	Rest of Sub Saharan Africa
11	Raw milk		
12	Wool, silk-worm cocoons		**Other regions**
		13	Canada, USA, Mexico
	Other industries	14	EU-25
13	Forestry, Fishing, Coal, Oil, Gas, Minerals nec	15	Japan
14	Bovine meat products	16	Norht East Asia (China, Hong Kong, Korea, Taiwan)
15	Meat products nec		
16	Vegetable oils and fats		
17	Dairy products	17	South East Asia (Indonesia, Malaysia, the Philippines, Singapore, Thailand, Vietnam, Rest of East and South East Asia)
18	Processed rice		
19	Sugar		
20	Food products nec		
21	Beverages and tobacco products		
22	Textiles, Wearing apparel, Leather products		
23	Other manufacturing	18	South Asia (Bangladesh, India, Sri Lanka, Rest of South Asia)
24	Electricity, Gas manufacture and distribution, Water, Construction		
25	Trade and Transportation services	19	Rest of the World
26	Other Services		

Notes: SACU is the South African Customs Union: South Africa, Botswana, Lesotho, Namibia, and Swaziland.
SADC is the Southern Africa Development Community.

Table 2. Welfare impacts of agricultural R&D investment budget allocations in sub-Sahara Africa, based on frontier A in Figure 5

	Simulation (productivity shocks for crops, and for livestock, in percent)										
	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11
Region	(10, 0)	(9, 1.855)	(8, 3.52)	(7, 4.995)	(6, 6.28)	(5, 7.375)	(4, 8.28)	(3, 8.995)	(2, 9.52)	(1, 9.855)	(0, 10)
					------------ *USD million* -----------						
Botswana	16.1	18.1	19.6	20.8	21.6	22.0	21.9	21.5	20.8	19.6	18.1
South Africa	373.0	417.5	451.5	475.6	490.6	496.8	494.6	484.4	466.3	440.6	407.2
Rest of SACU	43.2	44.2	44.6	44.3	43.4	41.9	39.8	37.2	34.0	30.2	25.9
Malawi	77.5	70.8	63.9	56.9	49.7	42.4	34.9	27.3	19.6	11.8	3.8
Mozambique	61.2	57.5	53.5	49.1	44.4	39.4	34.1	28.5	22.6	16.4	9.9
Tanzania	390.0	360.1	328.7	296.0	262.0	226.7	190.2	152.6	113.9	74.0	33.0
Zambia	60.4	57.1	53.5	49.4	45.0	40.3	35.2	29.8	24.1	18.1	11.7
Zimbabwe	150.1	146.2	140.9	134.3	126.4	117.4	107.1	95.8	83.3	69.7	55.0
Rest of SADC	201.1	200.4	197.2	191.5	183.5	173.3	161.0	146.5	130.0	111.5	91.0
Madagascar	99.9	103.6	105.4	105.5	104.0	101.0	96.5	90.6	83.4	74.8	64.9
Uganda	237.9	223.1	207.0	189.6	171.0	151.2	130.3	108.4	85.4	61.4	36.4
Rest of Sub Saharan Africa	2,582.3	2,513.4	2,418.5	2,299.3	2,157.3	1,993.8	1,809.7	1,605.7	1,382.5	1,140.3	879.5
Total for Sub-Sahara Africa	4,292.7	4,212.1	4,084.2	3,912.3	3,698.9	3,446.0	3,155.4	2,828.3	2,465.7	2,068.3	1,636.5
Canada, USA, Mexico	-61.5	-58.4	-54.7	-50.7	-46.2	-41.3	-36.1	-30.5	-24.6	-18.5	-12.0
EU-25	411.9	391.1	368.7	344.6	318.7	290.9	261.1	229.3	195.4	159.4	121.2
Japan	59.1	52.8	46.6	40.4	34.4	28.4	22.5	16.7	11.0	5.4	-0.1
Norht East Asia	40.4	37.8	35.0	32.2	29.3	26.2	23.0	19.7	16.3	12.8	9.2
South East Asia	-36.5	-32.7	-28.8	-25.0	-21.1	-17.2	-13.3	-9.4	-5.5	-1.7	2.1
South Asia	18.9	16.5	14.3	12.1	10.0	8.0	6.1	4.2	2.4	0.6	-1.1
Rest of the World	220.4	206.8	192.2	176.5	159.8	142.1	123.6	104.3	84.2	63.3	41.7
Total for other regions	652.6	614.0	573.2	530.2	484.8	437.1	386.9	334.3	279.1	221.4	161.2

Table 3. Welfare impacts of a gricultural R&D investment budget allocations in sub-Sahara Africa, based on frontier B in Figure 5

	Simulation (productivity shocks for crops, and for livestock, in percent)										
	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10	b11
Region	(10, 0)	(9, 1.095)	(8, 2.08)	(7, 2.955)	(6, 3.72)	(5, 4.375)	(4, 4.92)	(3, 5.355)	(2, 95.68)	(1, 5.895)	(0, 6)
					------------ *USD million* -----------						
Botswana	16.1	16.7	17.0	17.1	17.0	16.6	15.9	15.1	14.0	12.6	11.0
South Africa	373.0	384.8	390.8	391.3	386.4	376.3	361.1	341.0	316.0	286.2	251.6
Rest of SACU	43.2	42.2	40.7	38.9	36.7	34.1	31.2	27.9	24.2	20.1	15.7
Malawi	77.5	70.5	63.3	56.1	48.7	41.2	33.7	26.0	18.2	10.4	2.4
Mozambique	61.2	56.7	52.0	47.0	41.8	36.4	30.8	24.9	18.9	12.6	6.2
Tanzania	390.0	357.2	323.5	288.8	253.1	216.6	179.2	140.8	101.6	61.5	20.6
Zambia	60.4	56.1	51.7	47.0	42.0	36.8	31.4	25.7	19.8	13.7	7.3
Zimbabwe	150.1	141.9	132.8	123.0	112.4	101.1	89.0	76.3	62.8	48.6	33.7
Rest of SADC	201.1	193.1	183.6	172.6	160.2	146.3	131.0	114.4	96.3	76.9	56.1
Madagascar	99.9	98.2	95.5	91.8	87.1	81.5	75.0	67.6	59.3	50.1	40.1
Uganda	237.9	220.0	201.2	181.6	161.2	140.0	118.0	95.2	71.7	47.4	22.4
Rest of Sub Saharan Africa	2,582.3	2,441.2	2,284.9	2,114.2	1,929.3	1,730.9	1,519.2	1,294.5	1,057.0	806.9	544.2
Total for Sub-Sahara Africa	4,292.7	4,078.6	3,837.1	3,569.3	3,275.9	2,957.8	2,615.4	2,249.3	1,859.8	1,447.1	1,011.3
Canada, USA, Mexico	-61.5	-57.3	-52.9	-48.1	-43.1	-37.8	-32.2	-26.4	-20.4	-14.2	-7.7
EU-25	411.9	382.2	351.6	320.0	287.4	253.9	219.3	183.7	147.1	109.4	70.7
Japan	59.1	52.8	46.5	40.4	34.3	28.3	22.4	16.7	11.0	5.4	-0.1
Norht East Asia	40.4	37.1	33.7	30.3	26.9	23.4	19.9	16.3	12.7	9.1	5.5
South East Asia	-36.5	-32.8	-29.1	-25.4	-21.6	-17.8	-14.0	-10.2	-6.5	-2.7	1.1
South Asia	18.9	16.6	14.4	12.3	10.3	8.3	6.3	4.5	2.7	0.9	-0.7
Rest of the World	220.4	203.3	185.6	167.4	148.6	129.4	109.6	89.3	68.6	47.5	25.9
Total for other regions	652.6	601.8	549.9	497.0	442.9	387.6	331.3	273.8	215.2	155.4	94.6

Table 4. Welfare impacts of agricultural R&D investment budget allocations in sub-Sahara Africa, based on frontier C in Figure 5

	Simulation (productivity shocks for crops, and for livestock, in percent)										
	c1	**c2**	**c3**	**c4**	**c5**	**c6**	**c7**	**c8**	**c9**	**c10**	**c11**
Region	(10, 0)	(9, 0.715)	(8, 1.36)	(7, 1.935)	(6, 2.44)	(5, 2.875)	(4, 3.24)	(3, 3.535)	(2, 3.76)	(1, 3.915)	(0, 4)
					----------- *USD million* -----------						
Botswana	16.1	16.0	15.7	15.2	14.6	13.8	12.9	11.8	10.5	9.0	7.4
South Africa	373.0	368.3	360.0	348.1	332.7	313.9	291.8	266.3	237.6	205.6	170.3
Rest of SACU	43.2	41.2	38.8	36.2	33.3	30.2	26.8	23.1	19.2	15.0	10.6
Malawi	77.5	70.3	63.0	55.7	48.2	40.6	33.0	25.3	17.5	9.6	1.6
Mozambique	61.2	56.3	51.2	45.9	40.5	34.8	29.0	23.1	17.0	10.7	4.2
Tanzania	390.0	355.8	320.8	285.0	248.6	211.3	173.4	134.6	95.2	55.0	14.0
Zambia	60.4	55.7	50.8	45.7	40.4	35.0	29.3	23.5	17.5	11.3	5.0
Zimbabwe	150.1	139.7	128.7	117.2	105.2	92.7	79.7	66.2	52.2	37.7	22.8
Rest of SADC	201.1	189.4	176.7	163.0	148.2	132.4	115.6	97.7	78.8	58.9	38.0
Madagascar	99.9	95.5	90.5	84.8	78.5	71.5	63.8	55.6	46.7	37.3	27.2
Uganda	237.9	218.4	198.3	177.5	156.2	134.2	111.6	88.4	64.6	40.1	15.1
Rest of Sub Saharan Africa	2,582.3	2,404.7	2,217.0	2,019.2	1,811.8	1,594.7	1,368.1	1,132.2	886.9	632.4	368.6
Total for Sub-Sahara Africa	4,292.7	4,011.3	3,711.4	3,393.6	3,058.1	2,705.2	2,335.0	1,947.8	1,543.7	1,122.6	684.7
Canada, USA, Mexico	-61.5	-56.8	-51.9	-46.7	-41.4	-35.9	-30.1	-24.2	-18.1	-11.8	-5.3
EU-25	411.9	377.8	343.1	307.9	272.2	235.9	199.1	161.7	123.8	85.4	46.4
Japan	59.1	52.8	46.5	40.4	34.3	28.3	22.4	16.6	11.0	5.4	-0.1
Norht East Asia	40.4	36.7	33.0	29.4	25.7	22.0	18.3	14.6	11.0	7.3	3.6
South East Asia	-36.5	-32.9	-29.2	-25.5	-21.8	-18.1	-14.4	-10.6	-6.8	-3.1	0.7
South Asia	18.9	16.7	14.5	12.4	10.4	8.4	6.5	4.7	2.9	1.1	-0.5
Rest of the World	220.4	201.5	182.3	162.8	142.9	122.8	102.3	81.5	60.4	39.1	17.5
Total for other regions	652.6	595.8	538.5	480.6	422.3	363.5	304.1	244.4	184.1	123.4	62.3

Table 5. Welfare impacts of agricultural R&D investment budget allocations in sub-Sahara Africa, based on frontier D in Figure 5

	Simulation (productivity shocks for crops, and for livestock, in percent)										
	d1	**d2**	**d3**	**d4**	**d5**	**d6**	**d7**	**d8**	**d9**	**d10**	**d11**
Region	(10, 0)	(9, 0.335)	(8, 0.64)	(7, 0.915)	(6, 1.16)	(5, 1.375)	(4, 1.56)	(3, 1.715)	(2, 1.84)	(1, 1.935)	(0, 2)
					----------- *USD million* -----------						
Botswana	16.1	15.3	14.3	13.3	12.3	11.1	9.8	8.4	7.0	5.4	3.7
South Africa	373.0	351.7	328.8	304.2	278.0	250.2	220.7	189.6	156.8	122.5	86.5
Rest of SACU	43.2	40.1	36.9	33.4	29.9	26.2	22.3	18.3	14.1	9.8	5.3
Malawi	77.5	70.2	62.7	55.2	47.7	40.0	32.3	24.5	16.7	8.8	0.8
Mozambique	61.2	55.9	50.4	44.8	39.1	33.2	27.3	21.2	15.0	8.6	2.1
Tanzania	390.0	354.3	318.1	281.3	243.9	205.9	167.4	128.2	88.5	48.1	7.1
Zambia	60.4	55.2	49.8	44.4	38.8	33.1	27.3	21.3	15.2	8.9	2.5
Zimbabwe	150.1	137.4	124.6	111.4	97.9	84.2	70.2	56.0	41.4	26.6	11.5
Rest of SADC	201.1	185.7	169.8	153.2	136.0	118.1	99.7	80.6	60.8	40.4	19.3
Madagascar	99.9	92.8	85.4	77.7	69.6	61.2	52.4	43.2	33.8	24.0	13.8
Uganda	237.9	216.9	195.3	173.4	151.0	128.3	105.0	81.4	57.2	32.7	7.7
Rest of Sub Saharan Africa	2,582.3	2,368.0	2,148.2	1,922.7	1,691.7	1,455.0	1,212.8	965.0	711.5	452.3	187.4
Total for Sub-Sahara Africa	4,292.7	3,943.5	3,584.3	3,215.0	2,835.8	2,446.5	2,047.1	1,637.6	1,218.0	788.1	347.8
Canada, USA, Mexico	-61.5	-56.3	-50.9	-45.3	-39.7	-33.9	-27.9	-21.8	-15.6	-9.2	-2.7
EU-25	411.9	373.4	334.8	296.0	257.2	218.3	179.4	140.3	101.2	62.1	22.9
Japan	59.1	52.8	46.5	40.4	34.3	28.3	22.4	16.7	11.0	5.4	-0.1
Norht East Asia	40.4	36.3	32.4	28.4	24.5	20.6	16.8	13.0	9.2	5.5	1.8
South East Asia	-36.5	-32.9	-29.3	-25.7	-22.0	-18.4	-14.7	-10.9	-7.2	-3.4	0.3
South Asia	18.9	16.7	14.6	12.6	10.6	8.6	6.7	4.9	3.1	1.4	-0.3
Rest of the World	220.4	199.7	179.0	158.1	137.1	116.0	94.8	73.5	52.0	30.5	8.9
Total for other regions	652.6	589.8	527.1	464.4	402.0	339.7	277.5	215.5	153.7	92.1	30.8

Table 6. Cattle production impacts of agricultural R&D investment budget allocations in sub-Sahara Africa, based on frontier B in Figure 5

	Simulation (productivity shocks for crops, and for livestock, in percent)										
	b1	**b2**	**b3**	**b4**	**b5**	**b6**	**b7**	**b8**	**b9**	**b10**	**b11**
Region	(10, 0)	(9, 1.095)	(8, 2.08)	(7, 2.955)	(6, 3.72)	(5, 4.375)	(4, 4.92)	(3, 5.355)	(2, 95.68)	(1, 5.895)	(0, 6)
					----------- *percent* ----------						
Botswana	0.58	2.41	4.08	5.57	6.88	8.00	8.93	9.65	10.18	10.50	10.61
South Africa	0.42	0.71	0.96	1.17	1.35	1.50	1.61	1.69	1.74	1.75	1.73
Rest of SACU	2.34	3.05	3.67	4.20	4.63	4.97	5.21	5.34	5.37	5.30	5.12
Malawi	7.31	6.48	5.66	4.84	4.03	3.24	2.44	1.66	0.88	0.10	-0.67
Mozambique	4.33	4.58	4.75	4.84	4.85	4.78	4.64	4.42	4.13	3.76	3.32
Tanzania	4.71	4.29	3.88	3.45	3.02	2.58	2.14	1.68	1.21	0.73	0.24
Zambia	3.22	3.21	3.17	3.08	2.96	2.80	2.60	2.37	2.11	1.81	1.49
Zimbabwe	-0.07	0.65	1.34	1.99	2.59	3.12	3.60	4.00	4.32	4.56	4.71
Rest of SADC	1.96	2.37	2.70	2.96	3.16	3.29	3.36	3.37	3.32	3.21	3.04
Madagascar	2.52	2.63	2.70	2.72	2.70	2.65	2.55	2.42	2.25	2.04	1.79
Uganda	7.49	7.21	6.86	6.46	6.00	5.49	4.92	4.30	3.63	2.91	2.14
Rest of Sub Saharan Africa	2.48	2.57	2.62	2.63	2.60	2.53	2.43	2.30	2.12	1.92	1.68

Note: Cattle is industry no 9: Bovine cattle, sheep and goats, horses.

Table 7. Welfare impacts of agricultural R&D investment budget allocations in sub-Sahara Africa, based on frontier A in Figure 5

	Simulation (productivity shocks for food crops, and for livestock, in percent)										
	e1	**e2**	**e3**	**e4**	**e5**	**e6**	**e7**	**e8**	**e9**	**e10**	**e11**
Region	(10, 0)	(9, 1.855)	(8, 3.52)	(7, 4.995)	(6, 6.28)	(5, 7.375)	(4, 8.28)	(3, 8.995)	(2, 9.52)	(1, 9.855)	(0, 10)
					-----------*USD million* ----------						
Botswana	15.1	17.2	18.9	20.1	21.0	21.4	21.5	21.2	20.5	19.5	18.1
South Africa	240.9	298.1	344.8	381.9	409.9	429.3	440.4	443.6	439.0	426.9	407.2
Rest of SACU	20.0	23.1	25.6	27.6	28.9	29.8	30.0	29.8	29.0	27.7	25.9
Malawi	22.6	21.3	19.9	18.3	16.6	14.8	12.8	10.7	8.5	6.2	3.8
Mozambique	34.3	33.2	31.7	29.9	27.9	25.5	22.9	20.0	16.9	13.6	9.9
Tanzania	207.2	194.8	181.2	166.4	150.4	133.4	115.3	96.2	76.2	55.1	33.0
Zambia	30.0	29.6	28.8	27.7	26.3	24.6	22.6	20.3	17.7	14.8	11.7
Zimbabwe	34.2	41.8	47.9	52.8	56.5	59.0	60.4	60.6	59.8	57.9	55.0
Rest of SADC	98.1	107.0	113.5	117.8	119.8	119.8	117.8	113.9	108.1	100.5	91.0
Madagascar	50.3	58.6	65.2	70.2	73.6	75.5	76.0	75.2	73.0	69.6	64.9
Uganda	185.8	176.2	165.4	153.2	139.9	125.4	109.8	93.0	75.2	56.3	36.4
Rest of Sub Saharan Africa	1,253.8	1,312.3	1,346.1	1,357.1	1,346.5	1,315.5	1,265.0	1,195.8	1,108.2	1,002.7	879.5
Total for Sub-Sahara Africa	2,192.3	2,313.2	2,389.0	2,423.0	2,417.3	2,374.0	2,294.5	2,180.3	2,032.1	1,850.8	1,636.4
Canada, USA, Mexico	-33.2	-32.6	-31.6	-30.2	-28.4	-26.4	-24.0	-21.4	-18.5	-15.4	-12.0
EU-25	228.4	226.8	223.4	218.2	211.0	201.7	190.2	176.4	160.4	142.0	121.2
Japan	42.4	37.8	33.2	28.8	24.4	20.2	16.0	11.8	7.8	3.8	-0.1
North East Asia	43.9	40.9	37.7	34.5	31.2	27.8	24.2	20.6	16.9	13.1	9.2
South East Asia	-12.1	-10.7	-9.3	-7.9	-6.5	-5.0	-3.6	-2.2	-0.7	0.7	2.1
South Asia	11.5	10.0	8.5	7.1	5.8	4.5	3.3	2.1	1.0	0.0	-1.1
Rest of the World	89.5	89.3	87.9	85.5	82.0	77.5	72.1	65.8	58.6	50.6	41.7
Total for other regions	370.4	361.5	349.8	336.0	319.5	300.3	278.2	253.1	225.5	194.8	161.0

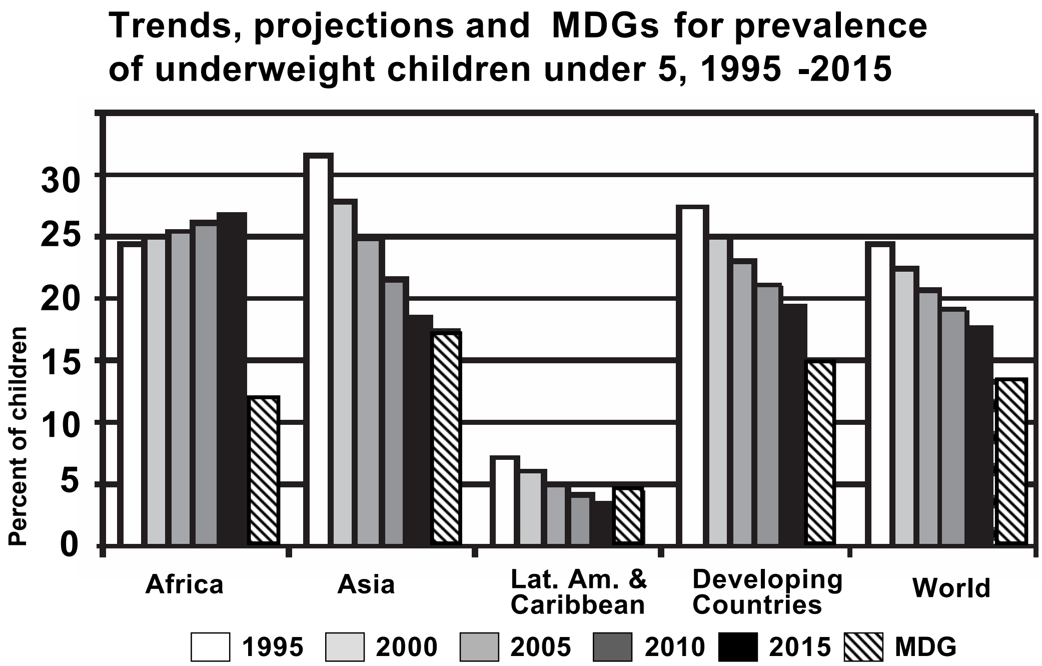
Table 8. Welfare impacts of agricultural R&D investment budget allocations in Botswana, based on frontier E in Figure 5

	Simulation (productivity shocks for food crops, and for livestock, in percent)										
	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11
Region	(10, 0)	(9, 2.805)	(8, 5.32)	(7, 7.545)	(6, 9.48)	(5, 11.125)	(4, 12.48)	(3, 13.545)	(2, 14.32)	(1, 14.805)	(0, 15)
	------------ *USD million* -----------										
Botswana	13.5	17.5	20.9	23.8	26.0	27.6	28.8	29.3	29.3	28.8	27.7
South Africa	-0.8	-0.7	-0.5	-0.4	-0.3	-0.1	0.0	0.1	0.2	0.3	0.5
Rest of SACU	0.0	0.0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3
Malawi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mozambique	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tanzania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zambia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zimbabwe	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Rest of SADC	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Madagascar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uganda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Sub Saharan Africa	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total for Sub-Sahara Africa	12.7	16.9	20.3	23.2	25.6	27.3	28.5	29.2	29.3	28.8	27.8
Canada, USA, Mexico	0.4	0.6	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.6	1.5
EU-25	1.3	8.0	14.1	19.6	24.5	28.7	32.1	34.7	36.7	37.8	38.1
Japan	0.3	0.5	0.7	0.9	1.1	1.2	1.3	1.3	1.4	1.4	1.4
North East Asia	0.3	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.7
South East Asia	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
South Asia	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of the World	0.4	2.1	3.6	5.0	6.2	7.2	8.0	8.7	9.2	9.4	9.5
Total for other regions	2.8	11.7	19.9	27.3	33.7	39.2	43.7	47.2	49.7	51.1	51.5

Table 9. Welfare impacts of economy-wide growth and agricultural R&D investment budget allocations in Botswana, based on frontier E in Figure 5

	Simulation (productivity shocks for food crops, and for livestock, in percent)										
	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11
Region	(10, 0)	(9, 2.805)	(8, 5.32)	(7, 7.545)	(6, 9.48)	(5, 11.125)	(4, 12.48)	(3, 13.545)	(2, 14.32)	(1, 14.805)	(0, 15)
	------------ *USD million* -----------										
Botswana	337.3	341.6	345.3	348.3	350.7	352.5	353.7	354.3	354.3	353.7	352.5
South Africa	14.7	14.9	15.0	15.2	15.3	15.4	15.6	15.7	15.8	15.9	16.0
Rest of SACU	-0.5	-0.5	-0.6	-0.6	-0.7	-0.7	-0.8	-0.8	-0.8	-0.8	-0.8
Malawi	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Mozambique	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Tanzania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zambia	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Zimbabwe	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Rest of SADC	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Madagascar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uganda	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Rest of Sub Saharan Africa	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
Total for Sub-Sahara Africa	351.1	355.5	359.2	362.3	364.8	366.7	368.0	368.7	368.8	368.3	367.2
Canada, USA, Mexico	0.9	1.2	1.4	1.6	1.8	1.9	2.0	2.1	2.1	2.1	2.1
EU-25	22.2	29.4	35.9	41.9	47.1	51.5	55.2	58.0	60.0	61.3	61.6
Japan	-0.4	-0.1	0.1	0.3	0.4	0.6	0.7	0.7	0.8	0.8	0.8
North East Asia	-0.6	-0.5	-0.4	-0.3	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1
South East Asia	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
South Asia	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Rest of the World	1.8	3.5	5.2	6.6	7.9	9.0	9.9	10.6	11.1	11.4	11.5
Total for other regions	23.1	32.6	41.4	49.3	56.2	62.1	66.9	70.6	73.2	74.7	75.1

Figure 1. Projections and Millennium Development Goals (MDGs) for



Source: UN Standing Committee on Nutrition (2004), *Fifth Report on the World Nutrition Situation*. New York: UN SCN.
Note: Data show estimated percentage of children aged 0 -5 who are underweight, defined as <2 s.d. below median NCHS weight for age.

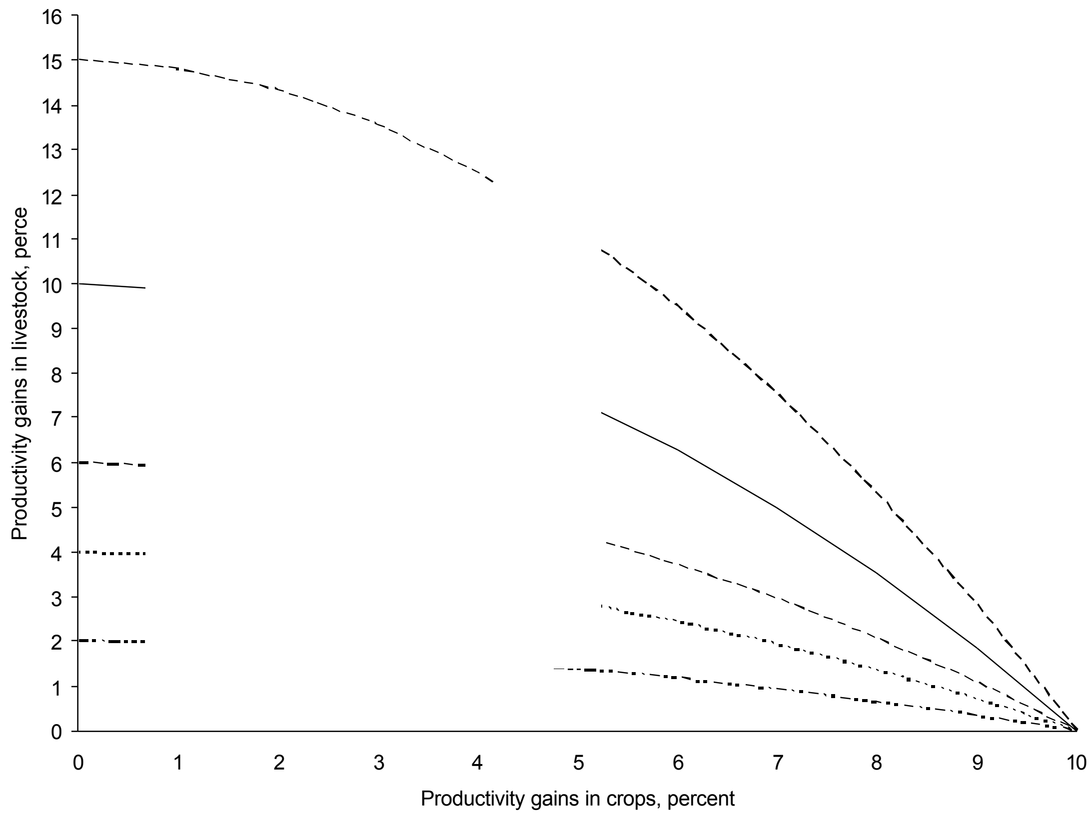
Borrowed from Masters (2005).

Figure 2: Food production per capita

Figure 3: Cereal yields

Figure 4: Beef yields

Figure 5. Trade-offs in Hicks-neutral productivity gains in crops and livestock in sub-Sahara Africa



Note: For some simulations, the scope of crops is narrowed to food crops.

Figure 6. Welfare gains from economy-wide growth and agricultural R&D investment in Botswana, USD million