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

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Abstract

Poverty is higher in most African countries than elsewhere in the developing world, and highest in the rural areas. Accelerating growth in agriculture will therefore be critical to sustain growth and reduce poverty, but policy makers are unsure which sub-sector will yield the highest return for a given budget. This paper uses an applied general equilibrium model to simulate productivity gains in sub-Saharan agriculture subject to trade-offs between gains in crops and gains in livestock. The simulated results suggest three conclusions. First, most sub-Saharan economies gain more from research and development (R&D) investment in crops than in livestock, though the SACU (South African Customs Union) economies and Madagascar benefit from sharing it between crops and livestock. Second, when R&D is focused on food crops, sharing investment between crops and livestock also benefits other economies. Third, in economies where sharing R&D investment between crops and livestock is beneficial (e.g. Botswana), general economic growth boosts the benefits from R&D investment in livestock.

Keywords: Agriculture; Livestock research; Development; Investment

La pauvreté est plus importante dans la plupart des pays africains que dans le reste des pays émergents et la plus élevée dans les zones rurales. Ce qui explique pourquoi l'accélération de la croissance en matière d'agriculture représente l'élément fondamental capable de maintenir la croissance et de réduire la pauvreté. Cependant les decideurs de politiques hésitent quant à savoir quel sous-secteur rapportera le plus dans le cas d'un budget donné. Cet article se base sur un modèle d'équilibre général appliqué afin de simuler des gains en matière de productivité de l'agriculture sub-saharienne sujette à des échanges entre les gains issus des cultures et ceux provenant de l'élevage. Les résultats de la simulation exposent trois conclusions. Premièrement, la majorité des économies sub-sahariennes bénéficient davantage de l'investissement dans la recherche et le développement (R&D) visant les cultures que celui visant l'élevage - bien que les économies de l'Union Douanière Sud-Africaine (SACU en anglais) et de Madagascar en bénéficient en le partageant entre les récoltes et le bétail. En second lieu, lorsque R&D se concentrent sur les cultures vivriaires, le partage de l'investissement entre les cultures et l'élevage fait également bénéficier d'autres économies. Troisièmement, dans les économies où l'on note un bénéfice du partage de l'investissement R&D entre les cultures et l'élevage (ex. le Botswana), la croissance économique générale renforce les bénéfices issus de l'investissement de R&D dans l'élevage.

Mots clés : *Agriculture ; Recherche en matière d'élevage ; Développement ; Investissement*

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1. Introduction

One of the development challenges of the 21st century is poverty in sub-Saharan Africa. Poverty is higher in most of these countries than elsewhere in the developing world: most have real growth rates of less than 5%, and about 40% of their population live on less than one US dollar a day. The groups most vulnerable to poverty live in rural areas, have large households that are often headed by women, and receive only limited education (World Bank 2000; Sachs 2005).

According to the Commission for Africa Report (2005), economic growth in Africa is necessary for meaningful reductions in poverty. The Commission for Africa recommends that African countries invest significantly in agriculture, because agriculture remains central to African economies, contributing at least 40% of exports, 30% of GDP, up to 30% of foreign exchange earnings, and 70 to 80% of employment. Accelerating growth in agriculture will therefore be critical to sustained growth and poverty reduction (Hazell, 2005). And since women play a major role in African agriculture, investing in agriculture will help combat the inequality they face in the region.

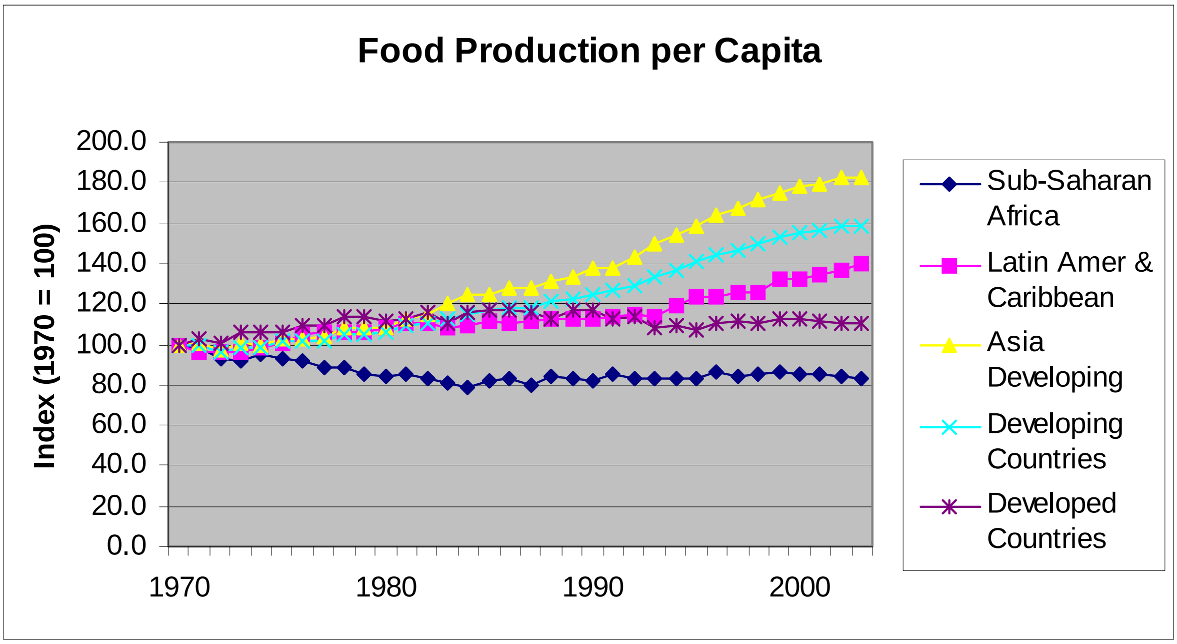
But although agriculture-led growth played an important role in the economic transformation of many Asian and Latin American countries and helped slash poverty, with a few exceptions this strategy has not worked in sub-Saharan Africa. As a result many sub-Saharan African countries still face national food constraints. The lessons from Asia and elsewhere are clear: there is a need for more research and development (R&D) investment in agriculture.

This paper aims to answer the following question: which agricultural sub-sector will yield the highest return for a given R&D budget? Since crops and livestock together constitute the largest share of the agricultural GDPs, it is useful to ask further questions. For a given amount of R&D funds, which will bring the higher returns to the economy: crops or livestock? Since achieving food security is a major policy challenge for many African countries, and since most R&D does not go to food crops, will R&D investment in food staples yield a higher return than comparable R&D investment in livestock? Because the decision to invest in a particular sub-sector may depend on the comparative importance of that sub-sector in a particular country, we apply this question particularly to Botswana, where livestock is more important than in any other sub-Saharan African country. Finally we ask 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 recent years have been in the order of 5–7% 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 and development and donor agencies are looking for ways to increase growth in Africa (see for example the recent report of the Commission for Africa, 2005).

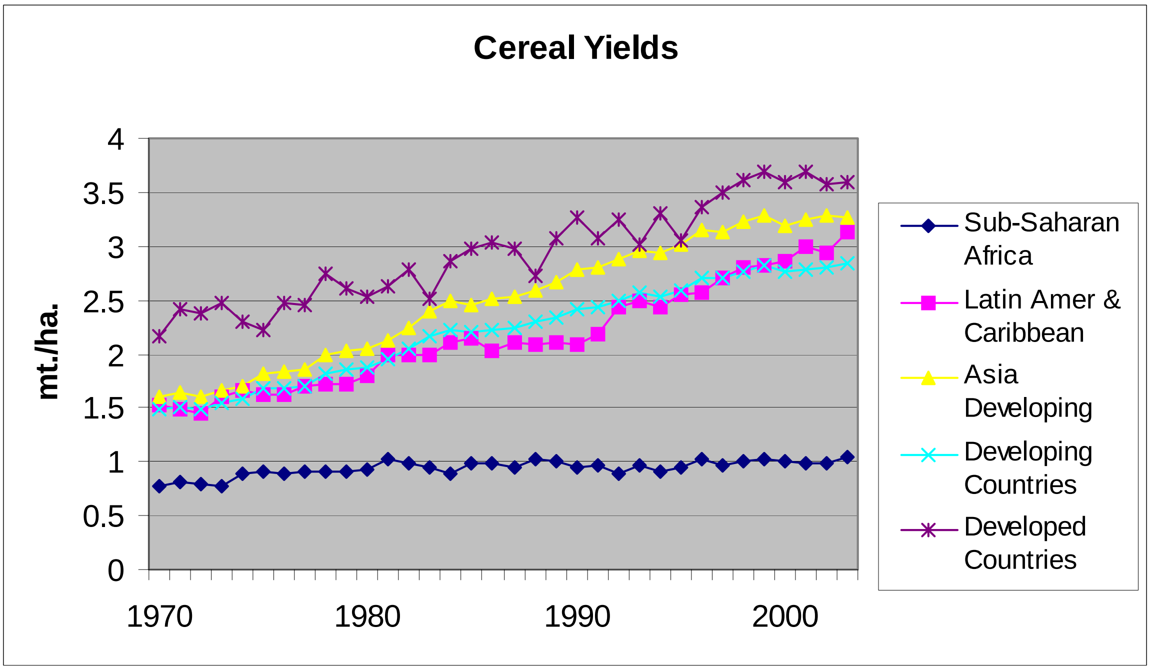
Second, while sub-Saharan Africa is blessed with abundant natural resources on a per capita basis, yields are so low that that there are plenty of opportunities to raise them through technological change. But funding for agricultural R&D in the region has been declining (Masters 2005). Consequently while agricultural output is growing, productivity is not (World Bank 2002). Food production per capita has declined 17% in sub-Saharan Africa from an already low level since 1970, the biggest decline of any major region of the world (Figure 1). Cereal yields have doubled in other regions of the developing world, yet in sub-Saharan Africa they have remained stagnant since the mid-1970s and now average only one third of yields in those regions (Figure 2). Yields of other food crops and livestock have also declined since the 1970s (World Bank 2000, 2002), beef yields by 10% (Figure 3). 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 (2003) and the Regional

Economic Communities (RECs), African Union heads of state and ministers have recognized the critical importance of agriculture as the cornerstone of the continent's sustained growth and poverty reduction.[1]



Source: Calculated from FAO statistics (www.fao.org)

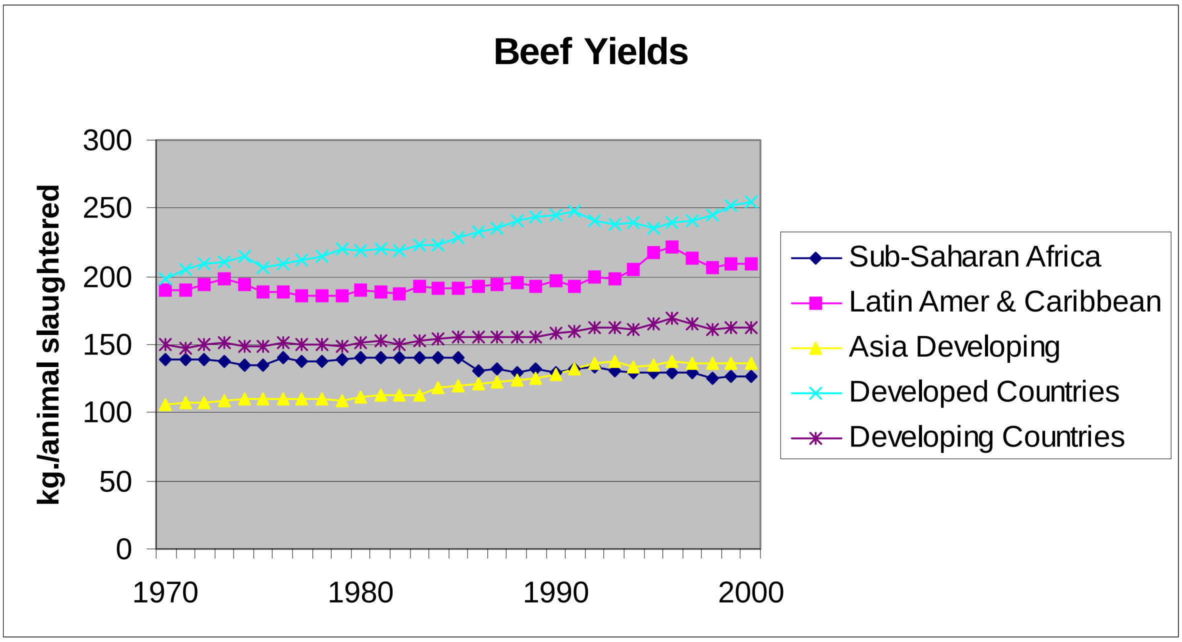
Figure 1: Food production per capita



Source: Calculated from FAO statistics (www.fao.org)

Figure 2: Cereal yields

[1] 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 (NEPAD 2001).



Source: Calculated from FAO statistics (www.fao.org)

Figure 3: Beef yields

2. Overview of the literature

Several studies have estimated high rates of return on agricultural R&D investment (for a review of these studies see Evenson & Rosegrant 1993). Impact studies (ex ante and ex post) are one way of providing convincing evidence that agricultural R&D has been or will be a good investment. Although a large number of studies have been completed globally, the number of studies carried out in sub-Saharan Africa is comparatively small.

The rate of return (RoR) approach is commonly applied to assess R&D investment in agricultural research. The RoR summarizes the benefits, costs and time frame of the R&D investment activity in a single measure. This approach makes it possible to compare returns on investments in research with returns on alternative investments. The RoR is easily compared with interest rates or other measures of the costs of obtaining funds, and in many cases it is also comparable across projects (Oehmke & Crawford 1993; Anandajayasekeram,et al. 1996). Generally RoR assessments for sub-Saharan Africa find positive returns on investment in agricultural R&D. A review of studies by Oehmke and Crawford (1993) shows positive returns ranging from 3% for cowpea research in Cameroon to 135% for maize in Mali. Masters et al. (1998) reviewed 32 estimates of RoR in Africa and found that only eight of the 32 studies report rates of returns below 20%. Their work confirms that rates of returns on research in sub-Saharan Africa are similar to those found elsewhere, showing high payoffs for a wide range of programs. They also found that payoffs are lower in lower-potential areas, which supports the argument for having different strategies for different development domains (Ehui & Pender 2005).

In terms of commodity focus, most studies of the returns on R&D investment have focused almost exclusively on crops, with only limited comparisons with livestock. This is unsurprising since, globally, evaluations have overwhelmingly focused on crop research (Alston et al. 2000), in which much of the benefit to date has been generated through varietal development, and also since livestock research is generally more difficult, slower and more costly than crop research. Its complexities are 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 projects 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 such as 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 combined crop-livestock projects and other projects with livestock components 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 in about 1955, has been one of the few success stories (Ngigi 2003; Omiti et al. 2005). Returns on milk and forage production have been consistently higher than the returns on crops such as beans and maize, a key factor explaining this success (Winrock International 1992). In the semi-arid zones of West Africa, where the introduction of animal traction began in the 1940s, the number of oxen almost doubled between 1979 and 1981–1983. This was made possible by the existence of profitable cash crops (cotton and groundnuts), effective input supply, and 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 the impact of R&D in agriculture, like any partial equilibrium approach it also presents some limitations. One is its assumption that prices and production of all other commodities are fixed. For example, the RoR approach would assume that changes in the cost of livestock production would not change the cost 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 their 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 them vulnerable to theoretical inconsistencies (Hertel 1990).

3. Data and methodology

We apply the GTAP (Global Trade Analysis Project) applied general equilibrium framework (Hertel 1997) to analyze the impact of agricultural R&D investment in sub-Saharan Africa. A global and economy-wide approach is most appropriate for this analysis. When certain agricultural industries gain in productivity, other agricultural sectors will 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, since the extent and conditions of international trade will determine the benefits accruing to a particular economy.

3.1 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 economy consists of several economic agents: on the final demand side, a utility-maximizing household purchases commodities and saves part of its income. On the production side, cost-minimizing producers employ primary factors and intermediate inputs to supply commodities. Demanders of commodities are assumed to differentiate a commodity by its region of origin, i.e. the Armington specification is applied (Armington 1969).[2]

Our analysis is based on aggregated data and parameters derived from the current GTAP database, version 6.0 (Dimaranan & 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 shown in Table 1. There are 26 industries and 19 regions. We focus our analysis on the 12 sub-Saharan African countries and regions identified in the GTAP and on eight crop and four livestock sectors.

3.2 Specification of simulations

Agricultural R&D investment is assumed to lead to increases in the productivity of crop and livestock activities, which then lead to economy-wide benefits. In particular, we model productivity gains in agriculture as Hicks-neutral technological change.[3] We take the simulated welfare effects from the AGE model as an indicator of returns on agricultural R&D investment.

For a given amount of R&D funds, we establish tradeoffs between productivity gains in crops and productivity gains in livestock. We assume that if an R&D budget is divided equally between crops and livestock, the resulting productivity gains in crops (or livestock) would be lower than if the R&D budget were devoted solely to crops (or livestock).

We perform three sets of simulations. First, we simulate different R&D allocations between crops and livestock. 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. This means that we do not consider productivity changes in sugar crops, plant fiber crops and other crops.[4] Third, we select Botswana, a country where livestock is a more important sector than in other sub-Saharan African countries, to study the food crops-livestock trade-offs.[5] For Botswana, we also examine the consequences of economic growth on agricultural R&D benefits.[6]

3.3 Tradeoffs in productivity gains from R&D

Lacking information to estimate trade-offs in crops-livestock productivity gains, we consider an R&D budget that would lead to a 10% productivity gain in crops, if all R&D were devoted to crops. We then ask the question: how much would livestock productivity increase if the whole R&D budget were devoted to livestock?

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[2] The GTAP model is solved using the GEMPACK suite of software (Harrison & Pearson 1994).

[3] 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 $r \in REG$

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

[5] Livestock is estimated to contribute 80% of agricultural value added in Botswana; food crops (maize, sorghum, millet and beans) account for the remaining 20%.

[6] Botswana is one of Africa's success stories of sustained economic growth: economic growth rates have averaged 5–7% per year in recent years (AfDB/OECD 2004).

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	North 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. The member states of the SACU are South Africa, Botswana, Lesotho, Namibia and Swaziland.

SADC is the Southern Africa Development Community. The member states of the SADC are Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe.

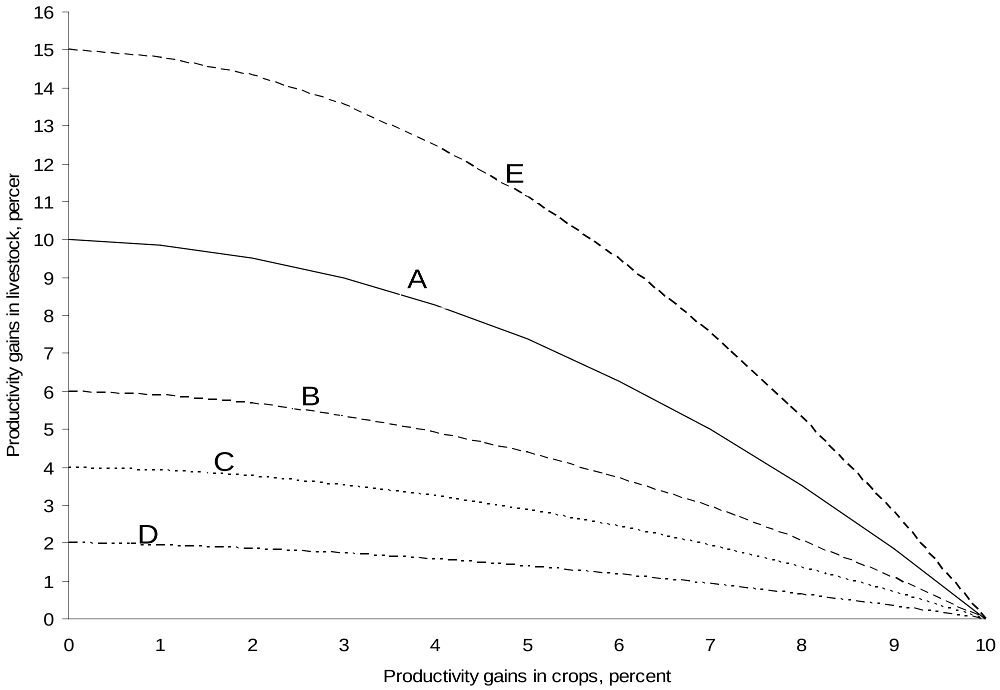
The model region ‘Rest of SACU’ is the aggregate of Lesotho, Namibia and Swaziland.

The model region ‘Rest of SADC’ is the aggregate of Angola, Democratic Republic of the Congo and Seychelles.

The model region ‘Rest of sub-Saharan Africa’ is the aggregate of Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Mali, Mauritania, Mayotte, Niger, Reunion, Rwanda, Saint Helena, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, Sudan and Togo.

The literature suggests that, for the same amount of R&D, productivity gains in livestock are more difficult to achieve than those in crops (Jarvis 1986; Winrock International 1992; Nin Pratt et al. 2005). For example, if certain R&D expenditures produce a 10% productivity gain in crops, the same R&D expenditure would produce a 6% or a 4% productivity gain in livestock. Since we do not have statistics to estimate this trade-off, we also consider a 10% and a 2% productivity gain in livestock, when all R&D is devoted to livestock.

Finally, we establish the intermediate points in the crops-livestock productivity gains trade-off by simply graphing the frontiers shown in Figure 4. We simulate different allocations of R&D by choosing different points on the frontiers in Figure 4. For example, assuming frontier A in Figure 4, if R&D is divided equally between crops and livestock, we simulate a 5% productivity gain in crops and a 7.375% productivity gain in livestock.[7] But if we assume frontier C in Figure 4, and an equal allocation of R&D to crops and to livestock, we would simulate a 5% productivity gain in crops and a 2.875% productivity gain in livestock. We simulate 11 R&D allocations for each of the four frontiers graphed in Figure 4.[8] Frontier E is used in the Botswana simulations.



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

Figure 4: Trade-offs in Hicks-neutral productivity gains in crops and livestock in sub-Saharan Africa

[7] 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.
[8] We perform four series of simulations for each sub-Saharan African economy. Each column in Tables 2 to 5 represents a different allocation of R&D investment between crops and livestock, and thus a different set of productivity gains. Column 'a1' in Table 2 represents the case where all R&D is devoted to crops and as a result productivity in crops increases by 10% in all sub-Saharan African regions. Column 'a2' in Table 2 represents the case where 90% of R&D is devoted to crops and the rest to livestock. As a result of this 90%/10% allocation of R&D, productivity in crops increases by 9% in all sub-Saharan African regions, and productivity in livestock increases by 1.885% in all sub-Saharan African regions. Column 'a11' in Table 2 represents the case where all R&D is devoted to livestock.

4. Findings

4.1 Crops vs livestock in sub-Saharan Africa

The simulated welfare effects suggest that, for sub-Saharan Africa, R&D in crops would generate higher welfare benefits than sharing R&D between crops and livestock (Tables 2 to 5). Even under the most favorable conditions for livestock, sub-Saharan Africa gains more from research in crops than from research in livestock (see Table 2). The largest welfare gains for sub-Saharan Africa occur in simulation 'a1'at the rate of $4293 million per year.

For South Africa and Botswana, however, welfare benefits peak at simulation 'a6' where crop productivity increases by 5% and livestock productivity by 7.4%. The Rest of SACU (simulation 'a6') and Madagascar (simulation 'a4') also benefit by sharing R&D between crops and livestock. Botswana and South Africa gain the most such sharing in Table 3 too (the 10% and 6% productivity scenarios for crops and livestock). In Tables 4 and 5, however, the other sub-Saharan African economies gain more from R&D in crops than in livestock. This result confirms conclusions reached in other research and is mainly driven by the relatively small GDP share of livestock in sub-Saharan African economies (Diao et al. 2006).

4.2 Food crops vs livestock in sub-Saharan Africa

Table 6 shows the welfare effects of R&D in sub-Saharan African food crops and livestock under frontier A in Figure 4.[9] As in Table 2, welfare gains for Botswana, South Africa, the Rest of SACU, and Madagascar peak at research budget allocations that share funds between food crops and livestock. Besides these four regions, three more benefit by sharing R&D between food crops and livestock: Zimbabwe, the Rest of SADC, and the Rest of sub-Saharan Africa. The countries that continue benefiting from R&D on crops are Malawi, Mozambique, Tanzania, Zambia and Uganda.

4.3 Botswana: Food crops and growth considerations

Table 7 shows the welfare effects of R&D investment in Botswana's food crops and livestock under frontier E in Figure 4.[10] As expected (from Table 6), Botswana benefits from sharing R&D expenditures between food crops and livestock. Welfare gains peak at simulation 'f9', which involves a higher percentage of R&D devoted to livestock than that implied by simulation 'e7' in Table 6.

To examine the consequences of economy-wide growth for the benefits of agricultural R&D in Botswana,[11] we simulate 7.5% growth in primary factors coupled with R&D in food crops and livestock (frontier E in Figure 4). The results of this simulation are shown in Table 8 and they suggest that welfare gains peak at simulation 'g9'.

A comparison of the welfare effects in Table 8 with those in Table 7 suggests that economic growth in Botswana makes R&D in livestock more valuable. This conclusion is based on the decomposition of welfare into three components, which are shown in Figure 5. The first component is the welfare benefit due to 7.5% growth in primary factors, which remains the same (i.e. US$323.783 million) for all R&D budget allocations. The second is the welfare benefit from agricultural R&D in the absence of economy-wide growth (as shown in Table 7). In Figure 5 the second component peaks at the ninth simulation. The third component is the impact of economy-wide growth on welfare benefits from R&D. The third component increases as more funds are allocated to livestock R&D investment and it peaks at the ninth simulation.

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[9] A significant share of crop production is assumed not to be the beneficiary of R&D in these simulations. Thus, for the simulations where crops gain in productivity, the sub-Saharan Africa welfare effects in Table 6 are smaller than those in Table 2.

[10] Frontier E in Figure 4 assumes that research in livestock can produce productivity gains (15%) that are larger than those produced by research devoted to food crops (10%).

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

Table 2: Welfare impacts of agricultural R&D investment budget allocations in sub-Saharan Africa, based on frontier A in Figure 4 (10% productivity gain in crops – 10% productivity gain in livestock)

	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)
	------------ *US$ 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-Saharan 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
North 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 agricultural R&D investment budget allocations in sub-Saharan Africa, based on frontier B in Figure 4 (10% productivity gain in crops – 6% productivity gain in livestock)

	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)
	------------ *US$ 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-Saharan 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	
EU-25	411.9	382.2		320.0	287.4	253.9	219.3	183.7	147.1	109.4	70.7
Japan		52.8	46.5	40.4	34.3	28.3	22.4	16.7	11.0	5.4	-0.1
North 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-Saharan Africa, based on frontier C in Figure 4 (10% productivity gain in crops – 4% productivity gain in livestock)

	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)
					------------ *US$ 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-Saharan 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
North 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-Saharan Africa, based on frontier D in Figure 4 (10% productivity gain in crops – 2% productivity gain in livestock)

	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)
					------------ *US$ 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 -Saharan 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
North 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: Welfare impacts of agricultural R&D investment budget allocations in sub-Saharan Africa, based on frontier A in Figure 4 (10% productivity gain in food crops – 10% productivity gain in livestock)

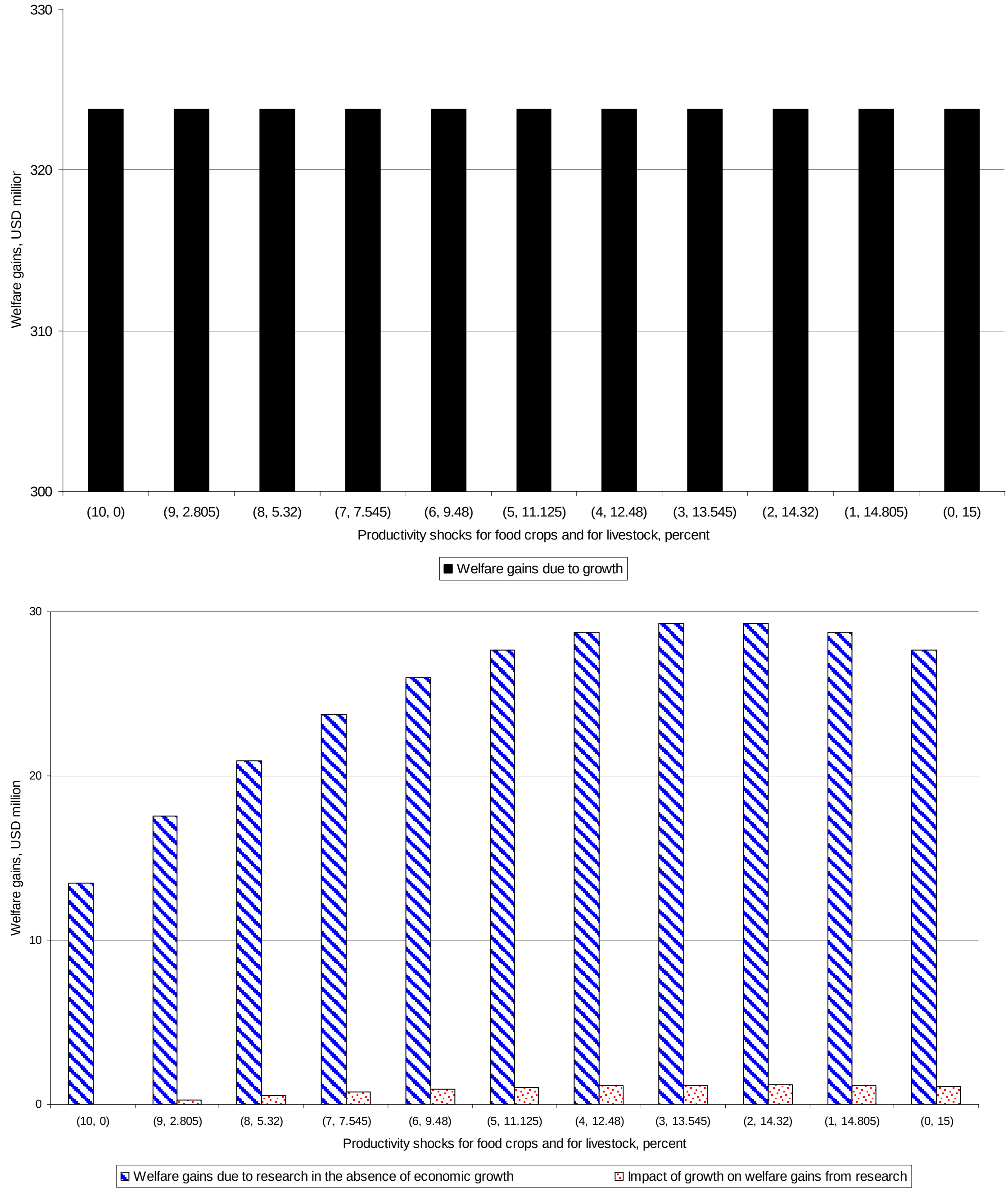
	Simulation (productivity shocks for food crops, and for livestock, in percent)										
	e1	**e2**	**e3**	**e4**	**e5**	**e6**	**e7**	**e8**	**e9**	**e10**	**e11**
Region	(10, 0)	(9, 1.855)	(8, 3.52)	(7, 4.995)	(6, 6.28)	(5, 7.375)	(4, 8.28)	(3, 8.995)	(2, 9.52)	(1, 9.855)	(0, 10)
	------------ *US$ 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-Saharan 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 7: Welfare impacts of agricultural R&D investment budget allocations in Botswana, based on frontier E in Figure 4 (10% productivity gain in food crops – 15% productivity gain in livestock)

	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)
					US$ 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-Saharan 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	1.5	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 8: Welfare impacts of economy-wide growth and agricultural R&D investment budget allocations in Botswana, based on frontier E in Figure 4 (10% productivity gain in food crops – 15% productivity gain in livestock)

	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)
	----------- *US$ 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-Saharan 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



Source: Authors

Figure 5: Welfare gains from economy-wide growth and agricultural R&D investment in Botswana, US$ million

5. Summary and conclusions

Our results suggest three conclusions. First, most of the sub-Saharan African economies gain more from R&D investment in crops than in livestock but this conclusion is not true everywhere**.** The economies of South Africa, Botswana, the Rest of SACU and Madagascar benefit from sharing research between crops and livestock. Second, when research is focused on food crops, sharing research funds between crops and livestock is beneficial to other economies too. Third, in economies where sharing R&D between crops and livestock is beneficial (e.g. Botswana), general economic growth increases the benefits from R&D 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 sub-Saharan Africa, domestic and foreign demand for these products is growing rapidly, providing ready market outlets for increased domestic production of these high value commodities (Hazell 2005). While there are opportunities for improving livestock and other non-traditional exports through better quality and niche markets, the 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.

This paper has two limitations. First the trade-offs between crops and livestock were not based on empirical information. Second, the rest of the sub-Saharan African region is at present not sufficiently disaggregated to permit more country-level analysis of the type we did for Botswana. There are certainly other countries in the Rest of sub-Saharan Africa where livestock output constitutes a large share of the agricultural GDP and where sharing R&D investment funds between crops and livestock may yield a 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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