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Prioritizing Agriculture-Related Research and Innovation for Growth and Poverty Reduction in Rwanda

by

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31 December 2018

Abstract

Agricultural research and development (R&D) has been found to be a powerful engine for poverty reduction worldwide. Based on experience in other countries, it seems likely that raising investment in agricultural from around 0.44 percent of agricultural GDP to the African Union target of 1 percent of agricultural GDP might increase agricultural productivity by around 50 percent. Such an increase in agricultural productivity could result in a decline in poverty of around 12 percentage points, from its current level of over 50 percent, with slightly larger poverty reduction gains for farmers than for other groups. For achieving such a goal, the allocation of research resources across commodities is an important question. If resources are allocated across commodities in line with their poverty-reduction impact, the poverty reduction gains are likely around twice as high as if they are allocated uniformly across commodities. In the specific context of Rwanda, it appears that allocating them in line with the value of output would give almost as large a gain as targeting their much-harder-to-evaluate poverty-reduction benefit.

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Prioritizing Agriculture-Related Research and Innovation for Growth and Poverty Reduction in Rwanda

Productivity growth is vital for economic growth and poverty reduction. Productivity growth in agriculture-related value chains is particularly important for low income countries such as Rwanda, where the large share of the work force and economic activity in agriculture makes the productivity of this sector central to determining national income and poverty rates. Obtaining this growth is difficult because it does not pay for individual farmers to invest substantial amounts in agricultural research—from which they will likely accrue a small share of the benefits. Policy makers in Rwanda recognize this challenge and have invested in generating key public goods in agricultural research and development. This decision to invest faces two key informational challenges: (i) how much to invest? and (ii) how to allocate these resources to particular crop and livestock activities for maximum impact?

A vast amount of research on the returns to investment in agricultural research and development (R&D) has found that these returns are generally extremely high both globally and in Sub-Saharan Africa (Fuglie 2018). High rates of agricultural productivity growth have also been found to strongly reduce poverty (Ivanic and Martin 2018). However, the effectiveness of investments in R&D in reducing poverty are likely to depend heavily on how they are allocated. Frequently, research resources are allocated primarily based on historical allocations or personal judgement. Byerlee (2000) and Contant and Bottomley (1988) suggest improving on these approaches by using simple principles such as: (i) congruence, where the objective is to align shares of research resources across crops in line with output value shares; (ii) checklists, where the focus is on identifying issues that will influence the impact of research or (iii) scoring approaches, where the answers to the questions identified in checklists are quantified to take into account relevant factors such as the probability of making advances in particular crops and the likely economic impacts of those advances.

Byerlee (2000) identifies the impacts of higher productivity on real incomes as determined by impacts on producer surplus; impacts on market prices and on wages. Janssen and Kissi (1997) develop methods for developing regional research programs that include these impacts and incorporate other key parameters such as the probability of success and the yield impact of successful interventions. None of the existing frameworks, however, calculates the effects of interventions on individual households in a way that allows assessment of their impacts both on growth and on the welfare of households. This is likely because—at the time they wrote—household surveys that identified their patterns of production and consumption were not widely available. Fortunately, large investments in surveys of the LSMS type mean that such information is now becoming widely available, including through up-to-date household surveys of Rwanda.

A key methodological innovation of this paper is its use, following Ivanic and Martin (2018), of data from household surveys to construct models that represent the impacts of productivity growth on the welfare of individual households. For some channels of effect, such as the direct impact of productivity growth on output at constant prices, household models alone are sufficient to fully represent the impacts. A more comprehensive assessment of the impact involves an assessment of whether the innovation changes commodity prices and wage rates, and hence generates somewhat less direct impacts on real incomes. Initially, we consider only first-order impacts of changes in productivity, where productivity growth increases output with existing resources, but for some large changes it is important to consider second-order impacts, where output increases because additional resources are drawn into the activity. The approach used allows us to consider not just changes in productivity in production agriculture, but changes in productivity in upstream or downstream sectors, that can have important impacts on income from agricultural activities (Freebairn, Davis and Edwards 1982).

The approach is designed to provide information as an input to decisions on research resources, rather than as providing a “magic bullet” that might provide a single solution to the complex problems of allocating research resources. However, this information—on questions such as which interventions are likely to have the largest impact on poverty reduction—seems likely to be very helpful to decision makers, whether they be traditional supply-side experts or those helping inform decision makers coming from the demand side (Lamers et al 2015).

In the next section of the paper, we look at the nature of investments in Rwandan Agricultural R&D and in upstream and downstream sectors, and at the apparent impacts of these investments, and potentially other changes, on indicator variables such as crop yields. In the third section, we examine the proposed methodology in more detail. Then, in the fourth section, we present results from our simulation analysis. In the fifth section, we consider the different role of government in policies for strengthening value chains and the ways in which such improvements can potentially reduce poverty. The final section presents some conclusions.

Background and Policy Issues

Rwanda has made substantial investments in agricultural R&D, primarily under the aegis of the Rwanda Agriculture and Animal Resources Development Board (RAB). In addition, policy makers are very interested in options for improving forward and backward linkages to agriculture through reforms such as those that have resulted in rapid expansion of coffee processing (Boudreaux 2011). Agricultural exports must also play an important part in achieving the high rates of growth in exports, and in the economy more generally, needed for Rwanda's economic development (English, McSharry and Ggombe 2016).

Rwanda's agricultural research system involves both a government agency (RAB) and researchers in academia (Fletcher, Beintema and Gatete 2018; Gahakwa et al 2014). Both funding and the number of researchers increased substantially between 2005 and 2016, although this period included a sharp increase up to 2014 followed by a decline between 2014 and 2016 as donor contributions dropped by nearly half, leaving agricultural research primarily dependent on government funding (Flaherty, Beintema and Gatete 2018). Despite the overall increase in funding over the 2005-2016 period, research spending as a share fell to 0.44 percent of agricultural GDP, considerably below the 1 percent goal recommended by the African Union and the United Nations. Spending on R&D has fallen sharply as a share of spending on agriculture. There is clearly a strong need for clear evidence on the benefits of agricultural research if funding is to increase in the future, perhaps with Rwanda's involvement in the Eastern and Central African Agricultural Transformation Project (ECAATP).

RAB distributes its resources across different program areas, such as cereals, bananas, pulses and oilseeds, aquaculture, monogastric and ruminant animals[2]. With current resources, there is a constraint on the number and size of programs as each should be led by a specialist

[2] See http://rab.gov.rw/fileadmin/user_upload/documents/RAB_Structure_2018.pdf

with advanced training and experience. From discussions with RAB officials, it appears that the program seeks broad coverage of the agricultural sector, but that the allocation of resources is not specifically targeted to goals such as poverty reduction or nutritional enhancement—possibly because of a lack of analytical tools to rigorously link resource inputs to these goals.

Rwanda has made agriculture a strong priority and has increased spending on agriculture in line with CAADP commitments, with agricultural spending accounting for between 9 and 13 percent of the budget in recent years (IPAR 2015). The impressive sector-wide plan for agricultural transformation (MINAGRI 2018a, p138) involves a further increase in spending coordinated by the Ministry of Agriculture and Animal Resources, although it leaves research and extension, with around 5 percent of total spending, less than the 6 percent allocated to extension. IPAR uses a broader definition of agriculture-related spending, which puts total spending on agriculture at 10.1 percent of total spending, about twice the share of the resources allocated to the Ministry of Agriculture and Animal Resources. Given the extensive evidence on the importance of R&D for sustained agricultural growth and poverty reduction (Fuglie 2018; Ivanic and Martin 2018), a key question is whether it would make sense to increase the share of R&D in total spending on agriculture from its current level of 0.44 percent out of this 10.1 percent.

In 2006-10, Rwanda was estimated to have only a very small share of total crop land, 7.1 percent, planted to improved varieties (Fuglie and Marder 2015, p346). This compared with 23.3 percent for Sub-Saharan Africa as a whole, 24 percent in East Africa, and 37.2 percent in Kenya. Fuglie and Marder (2015, p355) estimate the yield gains from adopting improved varieties as ranging from 24 percent for rice, to 55 percent for beans and 66 percent for cowpeas. While some of the adoption lag is perhaps due to the very wide range of agro-ecological niches in Rwanda, the combination of the adoption lag and high potential yield gains points to possibilities for very substantial progress simply by increasing adoption of varieties that are already available in the region. These opportunities have been recognized by the government, which plans to increase the number of agricultural experiment stations (Sabiiti 2018).

The impact of Rwanda's R&D program on livelihoods is greatly undermined by low rates of adoption of improved varieties. Although overall adoption rates are estimated to have risen to 11 percent in 2018, they remain very low for many key commodities, as is evident in Table 1.

Alarmingly for those concerned about the situation of small farmers seeking to compete with commercial farmers, these rates are frequently much higher for large-scale farmers (53.8 percent), defined as those cultivating at least 10 hectares, than for smallholders (10.2 percent). The problem does not appear to be one of smallholder inability to adopt improved varieties. As shown in Table 1, smallholder adoption rates for rice are nearly as high as for large-scale farmers, and are already around the government's target rate of 75 percent by 2024 (MINAGRI 2018a, p105). Smallholders also have adoption rates of over 25 percent for four other commodities: wheat, vegetables, maize and "other crops". Adoption rates are much higher—especially for larger farmers—for many of the eight priority commodities supported under the Crop Intensification Program (CIP), which involves facilitation of inputs (improved seeds and fertilizers), consolidation of land use, provision of extension services, and improvement of post-harvest handling and storage. USAID (2015), lists eight priority crops under this plan[3], including beans, banana, cassava, Irish potatoes, maize, rice, soybeans and wheat. For all these commodities except beans, adoption rates by large-scale farmers are over twenty percent. By contrast, adoption rates by small farmers exceeded 20 percent only for three of the targeted eight commodities—maize, rice, and wheat. Despite their designation as a priority crop under CIP and the availability of varieties with yields more than 50 percent higher than traditional varieties (SPIA 2014; Larochelle and Alwang 2014), adoption of improved varieties of beans remains low, even among large-scale farmers.

Table 1. Adoption Rates of Improved Varieties by Farm Size, 2018.

Crop	Large scale farmers	Small scale farmers
Paddy rice	78.7	72.2
Wheat	80.0	37.8
Vegetables	77.7	35.7
Maize	82.6	31.6
Other crops	46.7	26.5
Fruits	73.1	14.6
Dessert banana	51.6	5.5
Irish potato	30.6	4.1
Climbing bean	22.2	1.4
Bush bean	12.8	1.2

[3] The crops identified as priority depend on the agro-ecological conditions in this very geographically-diverse country, and sometimes include other commodities, such as tea.

Crop	Large scale farmers	Small scale farmers
Cassava	24.6	1.0
Banana for beer	42.1	0.9
Sweet potato	4.4	0.7
Pea	16.7	0.7
Soybean	51.4	0.7
Groundnut	-	0.4
Taro	-	0.2
Cooking banana	31.7	0.2
Sorghum	-	-
Small red bean	-	-
Yam	-	-
Other cereals	60.0	-
National	53.8	10.2

Note: Farmers cultivating 10 hectares and above are classified as large-scale. This accounts for 1.5% of cultivated area. Source: (MINAGRI, Seasonal Agricultural Survey, 2018)

As background to investigating the impacts of future productivity growth, we consider in Table 2 the share of area allocated to a range of crops and the past growth in the area and yield of these crops. Many factors influence yields and decisions about the area allocated to different crops. Other things equal, in a high-productivity growth environment, we might expect to find rapid growth in the area allocated to crops that for which productivity and yields are growing rapidly. If growth rates are sustained, then a large share of land allocated to high-growth commodities would ensure that overall growth is high in the future.

The picture revealed in Table 2 is quite different from this. Yields of some crops, such as Cassava and Yams, have grown substantially, while reported yields of other crops, such as sugar cane, soybeans, and rice have fallen. Some of this is due to special factors, such as a sharp decline in sugar cane yields in 2016 relative to the previous year and growth from trivial levels in 1995 to substantial areas in 2016 for rice and sugar. For two of the commodities with the highest yield growth—cassava and yams—the area has grown rapidly. However, the overall pattern is quite different from expectations in that the commodities to which more land has been allocated have generally not been the ones whose yields are rising. To some degree, this may reflect the extreme pressure on land resources in Rwanda and the need to increasingly move production onto more marginal areas (Diao et al 2010).

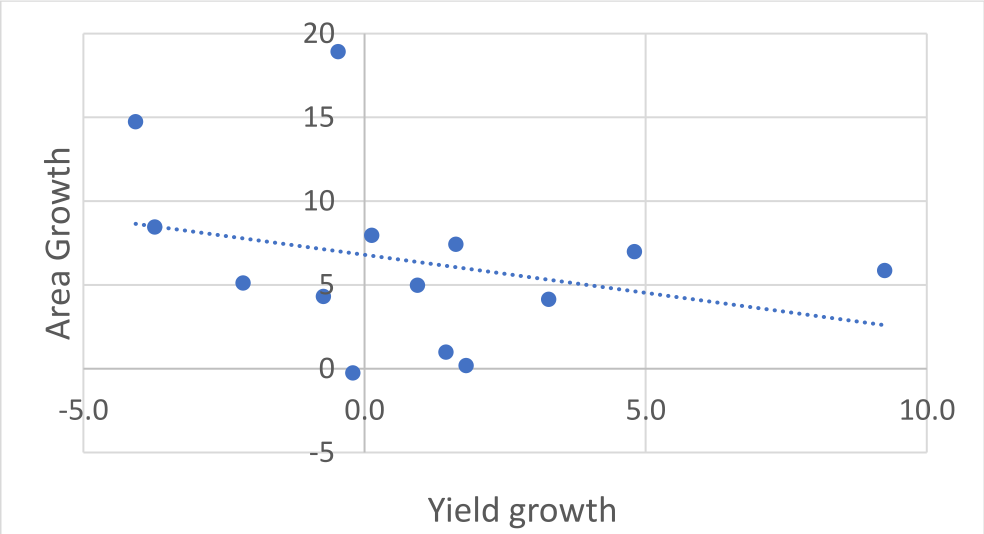
Table 2. Annual Growth in Yields, Area Harvested and Area Share in 2016, %

	Yield growth	Area growth	Area Share 2016
Bananas	1.8	0.2	17.5
Beans, dry	0.9	5.0	27.9
Cassava	9.2	5.9	11.2
Coffee	-0.2	-0.3	1.9
Maize	1.6	7.4	12.9
Potatoes	0.1	8.0	5.8
Pyrethrum	-2.2	5.1	0.2
Rice	-0.5	18.9	1.8
Sorghum	-0.7	4.3	9.0
Soybeans	-3.7	8.4	2.5
Sugar cane	-4.1	14.7	0.6
Sweet potatoes	1.4	1.0	7.4
Tea	3.3	4.1	0.9
Yams	4.8	7.0	0.4

Source: FAOSTAT Accessed 22 November 2018; Yield growth calculated as the annual change in the natural log of yields.

The relationship between yield and area growth is shown in Figure 1, together with a simple, linear trend showing a weak negative relationship between the two growth rates. Except for cassava, the growth rates for all the commodities accounting for more than 10 percent of harvested area have been under two percent per year. These results suggest that there is considerable scope for higher agricultural growth going forward if growth rates of yields could increase for larger commodities, and if areas allocated to different crops were to increase.

Figure 1. Yield and Area Growth in Rwandan Agriculture, by crop



Based on FAO data, Rwanda's growth in agricultural output between 1995 and 2016, measured at constant international prices, was 4.5 percent per year, with 0.9 percentage points of this growth accounted for by an expansion in agricultural land. Another important contributing factor to growth was an expansion of 1.9 percent per year in the area cropped, as the share of pasture land declined from 36 percent of agricultural land to 24 percent. The area harvested grew at 3.6 percent per year, pointing to higher frequency of multiple-cropping. Over the next quarter century, it is clear there will be much less scope for expansion of overall agricultural land, and less scope for transforming pasture land into arable land. Agricultural productivity growth will, as a consequence, become increasingly important as a source of overall agricultural output growth.

Rwanda appears to have considerable potential to increase the yields of many of its crop and livestock activities. To give some broad inkling of the possibilities, we compare reported yields in Rwanda with yields for Sub-Saharan Africa and the world in 2015. For most commodities, yields in Rwanda are comparable with averages for Sub-Saharan Africa, but considerably below world average levels. In this situation, there is scope for Rwanda to raise productivity both by reducing the gap between local yields and those of the most productive countries and by taking advantage of increases in productivity in the leading economies. The gap between Rwandan yields and the world average is particularly large for maize, soybeans and sugar. Maize yields in 2015 were roughly double their level in the mid-2000s, but below the 2.5 tons/ha recorded in 2014. For several commodities, including cassava and yams, Rwandan yields are similar to or exceed world levels, while rice yields are close to the world average. Coffee and tea, where quality is perhaps more important than quantity, have yields similar to the world average. Dry bean yields are close to the world average level, but recent research (SPIA 2014; Larochelle and Alwang 2014) points to potential gains from adoption of improved bean varieties in Rwanda of over 50 percent.

Table 3. Crop yields, t/ha harvested, 2015

	Rwanda	Africa	World
Bananas	9.4	10.9	21.2
Beans, dry	0.9	0.9	0.9
Cassava	16.6	9.2	11.8
Coffee, green	0.6	0.4	0.8
Maize	1.5	2.0	5.5

	Rwanda	Africa	World
Potatoes	10.1	14.7	19.9
Pyrethrum	0.4	0.5	0.5
Rice, paddy	3.2	2.5	4.6
Sorghum	1.0	1.0	1.6
Soybeans	0.5	1.3	2.7
Sugar cane	16.9	59.9	70.8
Sweet potatoes	6.7	5.1	12.5
Tea	1.5	1.7	1.4
Yams	9.3	8.9	8.9

Source: FAOSTAT accessed 22 November 2018

A large literature has examined the impacts of agricultural R&D on agricultural productivity in countries (Fuglie 2018). A key finding from this literature is that research investments can be treated like other investments, in that investments in research result in a stock of knowledge capital that can be built up and is subject to depreciation as predators and parasites devise ways to offset yield gains (Olmstead and Rhodes 2002). This literature includes lags between annual investments to reflect both the lags between investment and increases in productivity as scientific findings are made and new varieties disseminated. The relationship between research inputs and productivity eventually reaches a peak and then declines as the innovation becomes vulnerable to pests and/or is replaced by subsequent innovations. The weights applied typically sum to one so that a continuing investment in research results in a stable stock of research capital whose impact is captured by an elasticity estimated in econometric studies.

Many studies, reviewed in Fuglie (2018) and Laborde, Martin, Vos and Tokgoz (2018) suggest a mid-range elasticity of output with respect to research capital in Africa of around 0.2. These elasticities may be higher in the case of Rwanda because national agricultural research is needed to facilitate spill-ins of research findings from other countries and from the CGIAR's international research system. Research by Thirtle, Lin and Piesse (2003) found an elasticity of output with respect to research stock in Africa of 0.36 without allowing for spill-ins from external research. If we allowed for a spill-in from research undertaken in other countries of 0.08, this would imply a total elasticity of productivity with respect to research of 0.44. If Rwanda were to increase its investment in R&D from around its current 0.4 percent of the value of agricultural output closer to the African Union recommended level of 1 percent, this increase by a factor of 2.5 in the stock of research might result in an increase in productivity of 50 percent from current levels.

Basic Concepts in Assessing the Impact of Research

Given our interest in the gains in national income, exports and in poverty reduction, we first need to assess the extent to which an innovation either increases output for a given set of inputs or, equivalently, reduces the quantity of inputs needed to produce a given input. This assessment is usually presented as the quantity of output produced from a given quantity of value-adding factors, which defines the level of total factor productivity (TFP). This measure of productivity may differ from partial productivity measures such as yields per hectare, because yield can be increased without a rise in productivity as, for example, when farmers increase their use of fertilizer. TFP increases by one percent when the amount of output (measured as value added at constant prices) increases by one percent for the same factor inputs (land, labor and capital), while intermediate inputs (such as fertilizer, seeds and pesticides) change in line with output.

Agricultural productivity growth may take many forms other than TFP. Some innovations, such as many green-revolution crop varieties, save on land and labor, but require increases in intermediate inputs such as fertilizers. In this case, our assessment of the effect of the innovation must account for the additional intermediate inputs. Other innovations, such as BT cotton, may save on both factor and intermediate inputs. The increase in GDP resulting from an innovation that saves on both intermediate and factor inputs will be more than proportional with the saving in factor inputs. Not only does the increase in TFP increase national income proportionately, but the saving on intermediate inputs generates another round of increase in GDP. OECD (2001) provides a useful distinction between TFP calculated only using information on value added and what they call KLEMS multifactor productivity (MFP) calculated using measures of intermediate inputs as well as factor inputs. It also points out this is the most appropriate measure for productivity for individual sectors.

Because we are concerned about the impact of productivity changes on individual, poor households, we need to consider several issues beyond the direct impact of the productivity change on output of the good for which productivity has increased. The increase in productivity will increase the returns from producing this good, which will encourage firms to transfer resources from other activities into this activity. This generates a second-round benefit to the now-more-productive firms. If the increase in productivity is in a sector that is important in the economy—as agriculture is in Rwanda—there will be another impact through labor markets. If labor becomes more productive in Rwandan agriculture, one consequence will be an increase in the real wage rate. This change in the real wage rate is likely to be particularly important for low-skilled workers because Rwandan agriculture generally uses low-skilled labor. This increase in wage rates for unskilled workers may have important impacts for households that sell unskilled labor, both within agriculture and outside it. One of the key reasons that agricultural productivity growth is important for poverty reduction in low-income developing countries is that developing country agriculture is such an intensive user of low-skilled labor.

Another potentially-important channel of effect is through declines in the prices of agricultural goods. If increases in output of agricultural goods cause their prices to decline, the producers—both those benefiting from the productivity change and any unable to take advantage of the change—may face declines in output prices because of the increase in productivity. Because elasticities of demand for farm products tend to be low, such declines may translate into sharp losses for specialized producers who consume none of their output. The likelihood of loss is smaller for subsistence farmers who consume a large fraction of their output—the type of farmer that dominates Rwandan agriculture (Rwirahira 2009). For them, the first-order impact of the price change depends on whether they are net buyers or net sellers of the good. A household that remains a net buyer of the good even after the productivity increase will gain both from the increase in the productivity of its assets, and from the decline in the price of the goods that it buys. A household that is a net seller after the change will have two counteracting impact on its living standards—the increase in the productivity of its resources, and the loss in the value of its net sales.

These first-order impacts are not the end of the story. Households as producers will adjust their output mix to reduce the loss resulting from the decline in price. As consumers they will increase their consumption to increase the benefit from the fall in price. These second-order impacts also need to be considered. In the remainder of this section, we look at these effects in a little more detail to understand the impacts of productivity growth on the incomes of households, and particularly on households near the poverty line. We begin by considering how to represent the impact of technical change on the returns to producers, following the approach used by Martin and Alston (1997) and Ivanic and Martin (2018).

Under this approach, the impact of a technical change on profitability and output can usefully be represented using a distinction between actual and effective outputs. From the point of view of the firm, quantity q^* of effective output now translates into a larger quantity, q, of output, where $q = q^*\tau$. The first-order impact of this technological change on the value of output is given by the initial quantity times the change in τ, $\Delta\tau$. If the initial volume of output is 100 units and the change in technology raises output by 10 percent, then the first-order impact of the change in technology is the value of the 10 percent increase in output. The increase in the actual output from any given effective output results in an increase in the effective price of output at any actual price, where the effective price is defined as $p^* = p\tau$. The logic of this is very simple. If an innovation allows a farmer able to produce 110 units of output rather than 100, the effect on profits is the same as an increase in price of 10 percent.

Under this approach, production, profit and supply functions can be written in effective prices and, where relevant, quantities. If we begin by representing the objective of the producer with a quadratic profit function in effective prices:

(1) $$\Pi = \alpha_0 + \alpha' p^* + \frac{1}{2} p^{*\prime} A p^*$$

where Π is the potential net return at current factor prices, p^* is as defined above and the α and A terms are coefficients.

Differentiating (1) with respect to the effective price yields a supply curve for the output of good i:

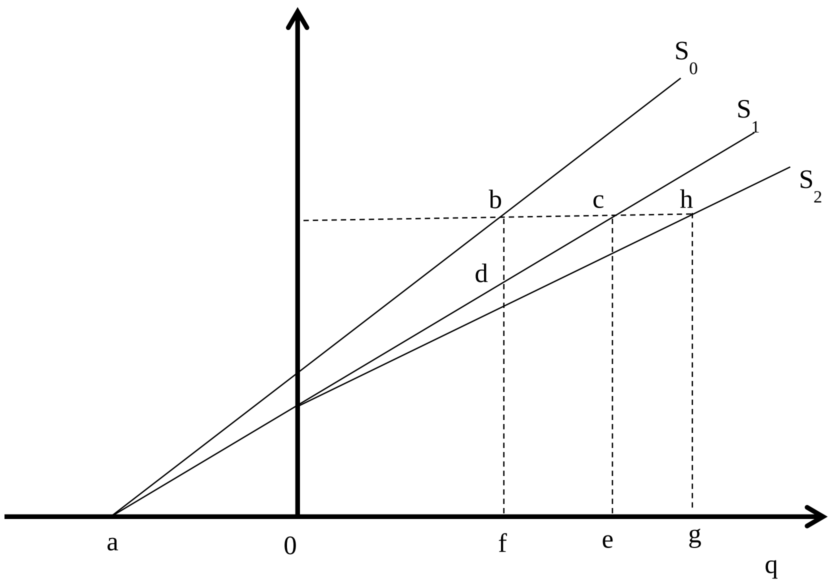
(2) $$q_i^* = \alpha_i + \sum_{ij} A_{ij} p_j^*$$

Transforming this into actual quantities and prices yields:

(3) $$q_i = \tau_i\left(\alpha_i + \sum_{ij} A_{ij}\, p_j \tau_j\right)$$

Equation (3) can be depicted in actual price and quantity space as in Figure 1.

Figure 2. Impacts of a productivity increase on output

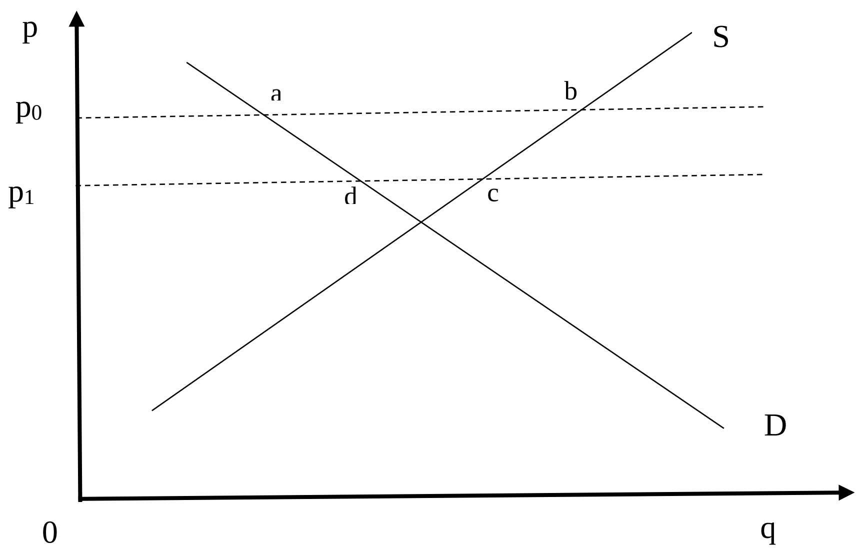


As can be seen from Figure 2, a rise in productivity has two effects on output at any given actual price. The first is an increase in output at any given input level. This increases output in the positive quadrant, and corresponds to the move from S_1 to S_2 in Figure 2.The second effect arises from the increase in profitability created by higher productivity, and is associated with the τ term within the parentheses on the right side of equation (3). It increases output at all prices above zero, and hence corresponds to the move from S_0 to S_1 in Figure 1. Note that this effect lowers the cutoff price at which positive quantities of output will be produced. As is clear from equation (3), the move from S_1 to S_2 is a proportional change in output (from e to g in Figure 1) that is independent of the slope of the supply curve. By contrast, the increase in output associated with the rise in effective price (from f to e in Figure 2) depends upon the slope of the supply curve as well as the size of the technological change.

The first source of change in output—the increase in output at a given level of inputs—has the first-order impact on welfare identified in our earlier discussion because it is "free." The second source of output increase comes about by attracting additional resources into the activity. It has a second-order impact on profits, because of the cost of the additional inputs used to obtain this increase in output. While it may seem intuitively reasonable to estimate only the total effect on output, the partial effect that allows identification of the technology change parameter, τ, is critical for welfare evaluation.

When a technological advance increases aggregate supply enough to lower the actual price of a good, the welfare impacts on households depend upon whether they are net sellers or net buyers, and upon their ability to adjust their output and consumption patterns. The impact of a price decline is shown in Figure 2 for a household that is a net seller of the good.

Figure 2. Welfare impacts of a price decline for a net seller of a good.



The curve marked S shows the household's supply of the good and curve D its demand. If this net-selling household were completely unable to change the quantity of the good that it produced or consumed, then the fall in price would cause it to lose $(p_0 – p_1)$.(b-a). Because it is able to reduce the amount it supplies and to increase its consumption, the net loss is given by area abcd. In this case of a net seller, the loss on the production side outweighs the households' gain on the consumption side. The case of a net buying household is the mirror image of the case shown. In this case, the gains to the household on the consumption side outweigh the losses on the production side.

Because increases in agricultural productivity raise wage rates for unskilled labor, we need to consider a similar set of impacts in the labor market. Because most households near the poverty line are either fully engaged in their own-account agricultural activities or are net sellers of labor to other people, the net seller case is the most relevant. In this case, the welfare impact depends on the quantity of labor that household members sell outside their own business activities and on their ability either to supply additional labor or to reallocate labor away from own-account activities to the labor market.

Analysis of Household Impacts

To estimate the impact of different productivity shocks on poverty, we need to estimate the impacts of productivity shocks on the economy and then on individual households. We use a Computable General Equilibrium (CGE) to assess the impacts on the national economy, and then turn to household models to assess the impacts on household welfare.

Economy-Wide Modeling

The CGE model that we use is the MIRAGRODEP model (Laborde, Robichaud and Tokgoz 2013; Bouët, Laborde and Traore 2017). It assesses the impacts on national output, product prices and wages CGE is model based on MIRAGE (Decreux and Valin 2007). This multi-country model allows a detailed and consistent representation of the economic and trade relations between countries—allowing us to capture the price impacts of productivity growth with and without trade agreements and, potentially, the impacts of trade agreements such as the African Continental Free Trade Agreement signed in Kigali in March 2018. International economic linkages are captured through international trade in goods and services, and through capital flows. A dynamic, recursive solution is obtained by solving the model sequentially and moving the equilibrium from one year to another. In our study we assume perfect competition in all sectors, which allows us to have a detailed geographic and sector decomposition.

In each country maximization of a CES-LES (Constant Elasticity of Substitution – Linear Expenditure System)[4] utility function by a representative consumer determines the allocation of expenditures across goods. The LES system allows for different income elasticities of demand, with those for food typically lower than those for manufactures and services. Once total consumption of each good has been determined in the top level, the origin of the goods consumed is determined by another CES nested structure following the Armington assumption.

[4] The CES-LES is a variant of a CES function where minimal consumption levels are introduced. It is equivalent to replacing the Cobb-Douglas structure of the Stone-Geary function (that is, LES) by a CES structure.

On the production side, value-added and intermediate goods are complements under the Leontief hypothesis that intermediate inputs are needed in fixed proportion to output. Total value added is represented as a CES function of unskilled labor and a composite of skilled labor and capital: this allows us to specify a lower degree of substitutability between the last two production factors. In agriculture and mining, production also depends on land and natural resources. To make the model behave in a manner comparable with the household model, where capital and land are not allowed to change, capital is fixed in each sector, so that output changes only in line with productivity changes and changes in the labor input. Skilled labor is perfectly mobile across sectors while unskilled labor is imperfectly mobile between the agriculture and non-agriculture.

Investment is savings-driven and the real exchange rate adjusts endogenously such that the current account is constant in terms of world GDP. As is common in modeling long-term productivity growth or trade reform, the supply of labor is treated as exogenous. While the supply of labor clearly adjusts to changes in wages in complex ways (Blundell and Macurdy 1998; Keane and Rogerson 2012), any resulting welfare gains are second-order, coming at the cost of reductions in nonmarket activities such as leisure.

The economy-wide model is used to estimate the impacts of productivity growth on commodity output, commodity prices, wages and other key variables. The changes in prices and wages are then passed to the household model, which determines their impact in conjunction with the change in productivity introduced into both the economy-wide model and the household models.

Household modeling

The analysis of household impacts uses micro-simulation models for each household represented in the Rwanda LSMS-based household survey EICV-4. Given the importance of smallholder agriculture in the Rwandan economy, an important feature of most of these household models is the inclusion of both agricultural production and consumption along the lines pioneered by Singh, Squire and Strauss (1986). Because farm households in Rwanda produce such a wide range of agricultural products—frequently because of the specificity of the agro-ecological conditions on their landholdings--and because we are interested in assessing more specific investments options than in many other studies, we have retained the full details of each household's agricultural production and consumption patterns, rather than forming representative households (see Bourguignon, Robillard and Robinson 2005).

A striking feature of Rwandan agriculture is the very limited dependence of agricultural producers on purchased farm inputs evident in both input-output tables for Rwanda (Pradesha and Diao 2017) and the household survey data. While the survey provides information on inputs used in crop and livestock production, it does not allocate inputs to individual crop or livestock activities. With purchased inputs making up only around 10 percent of the gross value of agricultural output for both crop and livestock producers, it did not seem worthwhile to maintain a complex, differentiated structure of intermediate inputs for each household. Accordingly, we used a composite structure of intermediate inputs for each household's production activities.

In line with standard practice in this type of model, the default setting is for intermediate inputs to be used in fixed proportion to outputs. We allow farm households to change their output mix in response to changes in relative prices, using an elasticity of transformation (Powell and Gruen 1968) which generates elasticities of supply for individual commodities in line with those used in other models, such as the EMM model used in Diao et al (2008). Developments, such as technological advances that increase profitability of the farm enterprise cause the household firm to demand more factors in order to increase farm output. Labor and other factor inputs are imperfect substitutes for land and capital inputs, with the ease of substitution specified using a constant elasticity of substitution function of the type typically used in general equilibrium models (Dervis, de Melo and Robinson 1982).

The model includes imperfect substitution between operator and family labor and hired labor used on farms. The family labor that is sold off-farm is also distinguished from family labor used on farm, because farm families carefully select the labor to be sold off-farm, taking advantage of specific skills for off-farm work. This allows the return to operator and family labor to adjust relative to the wage rate for hired labor, incorporating a distinction between the market wage rate and the shadow price of family labor emphasized in Singh, Squire and Strauss (1986).

These changes, in turn, determine whether individual households' income changes enough to move them over the poverty line. We do this by estimating the impact of productivity and price changes on farm incomes and taking into account the impacts of changes in wage rates on the incomes of households selling labor outside the farm firm. Finally, to estimate the impact of the change on the poverty rate, we calculate the share of households that have risen above the poverty line because of favorable shocks, and the share whose incomes have fallen enough to take them into poverty. For this analysis, we focused on the poverty line associated with the World Bank estimate of poverty in 2015, 51.3 percent[5]

Impacts of Productivity Growth

We consider two types of productivity growth in the analysis. The first is multi-factor productivity (MFP) that increases output by 50 percent for the same bundle of inputs, including factors and intermediate inputs. The second type is total factor productivity (TFP) that increases output from a given bundle of factors (land, labor and capital) while maintaining the initial relationship between the quantity of intermediate inputs and output. If both outputs and inputs increase by, say, 10 percent, value added at constant prices will also increase by10 percent. The MFP case corresponds to innovations like BT cotton, where output increases relative to both the factor and intermediate inputs (eg pesticides) needed to produce a given quantity of output. The TFP case perhaps corresponds more closely to many other innovations, which save land and/or labor per unit of output while requiring inputs to increase in line with (or even more rapidly than) outputs. Because we know that the price response to changes in productivity may be quite important, we repeat the MFP analysis with Armington elasticities—the elasticities that influence the responsiveness of export demand—that are 50 percent higher than the standard values in the model database. In each case, we consider four scenarios—increases in productivity in Agriculture, in Crops, in Maize and in Vegetables and Fruit.

Table 3 shows the impact of each set of shocks on four key economic outcomes, the rural wage, the consumer price index, the average producer price for the relevant commodity and the trade balance in agricultural products. The rural wage is important because the labor-intensive nature of Rwandan agriculture means that an expansion in agricultural productivity is likely to raise real wages considerably. It matters for welfare outcomes both because many poor households are net sellers of labor in rural labor markets, and because its movements are likely strongly linked to changes in the return to farm households' own labor on farm—their shadow

[5] This poverty rate was taken from Povcalnet under the "Replicate World Bank Regions" option. Accessed 28 November 2018.

wage. The CPI is also clearly very important because it influences the extent to which the costs of living fall for those not gaining directly from the improvement in productivity.

Table 3. Impacts of 50 % productivity increases on key economic variables.

	Elasticity	**Rural Wage**	**CPI**	**Producer Price**	**Ag Exports**
		%	%	%	$m
MFP Agriculture	High	13.2	-11	-22.6	382
MFP Crops	High	11.2	-10.9	-20.9	296
MFP Maize	High	0.9	-1.2	-21.2	26
MFP Veg Fruit	High	4.0	-10.8	-28.9	117
MFP Agriculture	Standard	10.5	-12.5	-25.3	303
MFP Crops	Standard	9.4	-11.9	-22.9	253
MFP Maize	Standard	0.9	-1.3	-21.3	24
MFP Veg Fruit	Standard	3.3	-11.2	-29.5	99
TFP Agriculture	Standard	6.0	-11.9	-21.7	277
TFP Crops	Standard	5.8	-11.4	-22.3	245
TFP Maize	Standard	0.6	-1.2	-20.1	24
TFP Veg Fruit	Standard	0.9	-10.6	-28	102

Source: Authors' model results.

The rise in rural wages is higher for innovations that increase both productivity in all of agriculture and for all crops than for the innovations confined to the much smaller maize and vegetable sectors. Most of the gain comes from increases in the productivity of crops, which make up a large share of agricultural output. Importantly, the gains from the MFP increases presented in the first block of the table are much larger than those from TFP presented in the first block, even though intermediate inputs make up a very small share of (around 12 percent) in total costs in Rwandan agriculture. This is because an MFP gain cumulates through the Input-Output table. A gain of 1 percent in TFP in all sectors is a 1 percent gain in GDP—if output is held constant in all sectors, 1 percent of factors are available for use in producing other goods.

By contrast, a one percent gain in MFP provides the same gain, plus a gain from the factors that are no longer needed to produce the intermediate inputs that have been saved.

The reduction in the CPI associated with productivity gains arises because productivity-induced increase in output push down the producer prices of output, as seen in column 2 of Table 3. This effect is very marked because MIRAGRODEP involves differentiation between the products produced by Rwanda and those of other countries. Further, Rwanda currently has no presence in many markets and this specification does not allow exports to grow to markets in which they are initially zero. The fall in producer prices is a loss to producers, but a gain to consumers, including the many households who both produce and consume agricultural goods. For the households who are net buyers of these goods, the fall in price provides a net gain in welfare, for those who are net sellers, it provides a source of loss to offset against the direct income gains from higher productivity.

The last column of the table shows the impact of the productivity shock on agricultural exports, within a context in which the current account overall is fixed. This shows that these increases in productivity do cause substantial increases in net agricultural exports even in this case, as agricultural products become more competitive than other agricultural products. If the current account closure allowed incomes to rise relative to expenditure, then the gains in agricultural exports would be bigger, with export growth not constrained by the exchange rate appreciation associated with expenditures rising in line with incomes.

The impacts within Table 3 are generally largest for the first block, where MFP shocks occur in a context of higher Armington elasticities. This is because the higher Armington elasticities allow exports to expand more, with smaller depressing impacts on producer prices. When we move to the standard Armington elasticities in the second block of the table, the gains in terms of wages fall and the losses in producer prices are larger. In the final block of the table, the gains are smaller. The losses resulting from producer price declines are also smaller, because the increase in productivity is not as large.

Poverty Impacts under the Armington Model

The key poverty impacts associated with the macroeconomic results for MFP increases in Table 3 are presented in Table 4. The top part of this table shows the percentage point change in poverty rates resulting from the standard case simulation while the lower part shows the simulation with higher Armington elasticities. The results show that the poverty reductions are slightly larger under the high-Armington elasticity assumption than under the standard elasticities. However, these differences are small, suggesting that these effects are robust to this difference. Under all scenarios, the benefits in terms of poverty reduction are greater for households headed by farmers and for rural people than for overall poverty rates. This is because farmers and many rural people obtain direct income gains from the productivity change, and these benefits are not completely offset by declines in producer prices which only have adverse impacts on the real incomes of net sellers, many of whom are not poor. Most of the differences between rows in Table 8.4 are due to differences in coverage. Crops has the broadest coverage and the largest benefit. Maize has the smallest coverage and the lowest poverty impact. Vegetables and Fruits has a surprisingly large impact, reflecting the importance of this group of products and the poverty of many of the farmers producing them.

Table 4. Changes in poverty rates for 50% MFP increase, percentage points

	Elasticity	**All**	**Farmer**	**Rural**
Agriculture	Standard	-10.6	-11.5	-12.0
Crops	Standard	-9.8	-10.7	-11.1
Maize	Standard	-1.3	-1.6	-1.5
Vegetables and Fruit	Standard	-7.0	-8.0	-8.0
Agriculture	High	-11.1	-12.0	-12.6
Crops	High	-10.1	-10.9	-11.4
Maize	High	-1.3	-1.5	-1.5
Vegetables and Fruit	High	-7.1	-8.1	-8.1

Source: Authors' simulation results.

A key question with poverty results such as those presented in Table 4 is the source of these gains. The changes in real incomes of households that give rise to the poverty change can be decomposed in different ways. Do they come directly from the boost to producer income resulting from the technological change, or do they come from the change in business income resulting from changes in productivity and prices, or are they realized when households benefit from a fall in their cost of living? Table 5 presents results that let us answer these questions.

The first section of the table shows that the reduction in poverty resulting from higher productivity—without any change in prices—would be very similar to the final results presented in Table 4. If we focus on the change in the value of sales of these products, taking into account both the increase in productivity and the fall in output prices, the reduction in poverty would be much smaller than the direct impact of the shock on farm incomes at constant prices. Adding reductions in input costs to get the impact on business incomes results in a slightly larger fall in incomes. Only when we consider the impact of the fall in prices on the cost of expenditure (including the fall in the opportunity cost of own-consumed food) are we able to explain the full reduction in poverty.

The overall reduction and the reduction in rural poverty are slightly higher than the reductions observed when considering only the direct impacts. However, the reduction for farmer-headed households is slightly smaller than the direct impacts of the productivity change on poverty because the decline in producer prices offsets the direct income gain for some net-selling farmers.

Table 5. Sources of poverty reduction, standard model, % points

Direct Impact	**All**	**Farmer**	**Rural**
Agriculture	-10.56	-13.43	-12.33
Crops	-9.09	-11.65	-10.71
Maize	-1.05	-1.45	-1.25
Vegetables & Fruit	-7.61	-9.76	-8.98
Sales Effect			
Agriculture	-2.44	-2.61	-2.75
Crops	-2.04	-2.17	-2.31
Maize	-0.2	-0.28	-0.25
Vegetables & Fruit	-0.34	-0.37	-0.42
Business Effects			
Agriculture	-2.61	-2.9	-2.97
Crops	-2.32	-2.56	-2.65
Maize	-0.4	-0.52	-0.49
Vegetables & Fruit	-0.26	-0.34	-0.33
Full Income			
Agriculture	3.82	-3.53	-4.23
Crops	-3.23	-3.05	-3.62
Maize	-0.45	-0.51	-0.53
Vegetables & Fruit	-0.3	-0.1	-0.33
Full Real Income			
Agriculture	-11.1	-12.0	-12.6
Crops	-10.1	-10.9	-11.4
Maize	-1.3	-1.5	-1.5
Vegetables & Fruit	-7.1	-8.1	-8.1

Detailed Poverty Impacts within Agriculture

The results presented in Table 5 are illuminating but don't provide an adequate guide for allocating resources between individual commodities. What is needed to help guide resource allocation between production of individual commodities is estimates of productivity impacts for sub-sectors. Table 6 presents these results for crops in total and for 19 individual crops. The first set of results focusses on the small-open-economy case where output prices are unaffected by the change. In this situation, the benefits from productivity growth arise only from the direct income effect of the productivity gain and any impact on wage rates. The remainder of the table is based on a situation like the results in the previous section—where output prices decline as supplies rise, and the welfare evaluation must incorporate the welfare impacts of these declines for both producers and consumers. In the small-open-economy case, the wage rate impacts are based on Stolper-Samuelson elasticities derived from the MIRAGRODEP model[6], scaled to the share of each commodity in total agricultural output. In the large-economy case, the price changes and wage rate changes are based on the effects of each of the broader sectors considered in the MIRAGRODEP analysis.

Interestingly, under both scenarios, the commodities with the largest poverty-reducing impacts are core staples, such as Pulses, Bananas, Irish Potatoes, Cassava and Sweet Potatoes. Under the small-open-economy scenario, these large impacts come from the poverty of many of the producers, and the labor intensity of the production process, that benefits farmers producing these commodities and unskilled workers who benefit from extra demand for their labor. Under the differentiated product case, where producer and consumer prices fall, a large part of the poverty reduction is associated with the fall in consumer prices of these products which, in turn, reduces poverty among poor consumers who spend a large share of their incomes on food. A surprising feature of both sets of results is the very small impact of productivity growth in export crops such as coffee, tea and pyrethrum. It seems likely that the growers who can afford the long lead time involved in producing coffee are generally above the $1.90 per day standard used in

[6] The Stolper-Samuelson elasticity shows the impact of commodity price changes on factor price changes. With an output-augmenting technical change, it is the effective commodity price change that creates the factor price change. The Stolper-Samuelson elasticity of wage rates with respect to agricultural output price changes was estimated to be 1.1.

this table. For tea, perhaps the effect is due to the commodity being produced largely by corporations, whose production activities do not show up in the household survey. However, the small areas devoted to these commodities seem to suggest that impacts through the labor markets are likely to be smaller than for commodities such as pulses that account for over 25 percent of harvested area.

Table 6. Poverty reduction Impacts of 50% productivity increases, % points

		With Differentiated Products				
	Small Economy	**Direct**	**Business**	**Business+ Wages**	**Full Income**	**Full Real Income**
All Crops	**-13.38**	-9.40	-2.02	-3.61	-3.00	-10.02
Banana/Plantains	**-1.66**	-1.16	-0.21	-0.36	-0.29	-1.05
Cassava	**-1.70**	-1.17	-0.20	-0.35	-0.26	-1.25
Coffee	**-0.19**	-0.12	-0.09	-0.12	-0.11	-0.12
Fruit	**-0.48**	-0.42	-0.06	-0.09	-0.07	-0.28
Irish Potato	**-1.94**	-1.19	-0.23	-0.57	-0.41	-1.34
Maize	**-1.24**	-0.88	-0.22	-0.32	-0.26	-0.84
Milk	**-0.34**	-0.34	-0.28	-0.28	-0.28	-0.28
Oilseeds	**-0.08**	-0.07	-0.01	-0.02	-0.01	-0.23
Pulses	**-2.86**	-2.17	-0.41	-0.76	-0.59	-2.01
Pyrethrum	**-0.01**	0.00	0.00	-0.01	-0.01	-0.01
Rice	**-0.30**	-0.26	-0.11	-0.13	-0.12	-0.39
Root crops	**-0.01**	0.00	0.00	-0.01	-0.01	-0.01
Sorghum	**-0.53**	-0.32	-0.06	-0.10	-0.09	-0.31
Sugar	**-0.06**	-0.05	0.00	-0.01	0.00	-0.11
Sweet Potato	**-1.99**	-1.57	-0.22	-0.35	-0.24	-1.38
Tea	**-0.04**	-0.03	-0.03	-0.04	-0.04	-0.04
Tobacco	**-0.01**	0.00	0.00	-0.01%	-0.01	-0.01
Vegetables	**-1.12**	-0.83	-0.15	-0.25	-0.19	-0.85
Wheat	**-0.03**	-0.02	0.00	-0.01	-0.01	-0.03

There are also concerns that it may be much more difficult to increase productivity in such highly traditional crops such as beans, cassava and sweet potatoes. This would not be surprising if there were no new varieties that could allow substantial increases in productivity. However, the literature on this question seems to suggest that introducing new varieties of beans and other staples can create substantial increases in productivity. SPIA (2014) argues that adopting already-available improved varieties of beans could raise household yields for beans by 53 percent in Rwanda. Larochelle and Alwang (2015) point out that higher adoption of improved beans could also improve nutritional outcomes, arguing that 65 percent of protein intake in Rwanda is from beans, against only 4 percent from animal-sourced foods. A key challenge, looking forward, is why there has been so little adoption of these innovations, despite the presence of improved varieties and the inclusion of beans and cassava in the list of priority products under the Crop Intensification Program.

The much larger impacts on poverty of the same change in productivity in each activity raise important questions about the allocation of research resources. If we focus on the small, open economy case, and assume that an equivalent investment in each commodity will generate the same increase in productivity, then allocating the same resources to all commodities would result in much higher returns, in terms of poverty reduction, for commodities such as beans and cassava than for commodities such as tea and coffee. Allocating more resources to the commodities where productivity growth has the largest impact on productivity will result in greater overall poverty reduction than under the uniform resources per commodity rule.

One simple approach to seeing how important the allocation of resources across commodities might be is to examine the relative impacts of different allocations across commodities. We do this by comparing the productivity growth resulting from three different allocations of resources:

(i) Equal across all commodities

(ii) In line with output (the congruence rule discussed by Byerlee (2000), and

(iii) In line with the productivity-enhancing impact of productivity growth in each sector.

Applying these allocations to the direct impacts of productivity growth yields three different estimates of the resulting impact on poverty. A key question is how large the differences in poverty reduction might be.

With enough resources to achieve a 50 percent increase in production of one good, or roughly a 5 percent increase in productivity in all goods, we consider the impact of changing the proportion of research allocated to each good. The results are given in Table 7.

Table 7. Poverty reduction impacts under different research allocations

Equal shares	-4.9
Output shares	-9.6
Productivity impact	-10.4

The table makes clear that allocating resources uniformly across sub-sectors is a highly-inefficient way of achieving rapid reductions in poverty. If, instead, resources are allocated based on commodity output value, then the reduction in poverty will be almost twice as large. The poverty-reduction impact of the R&D investment will be even greater if resources are allocated in line with the poverty reduction-impact of investments in that commodity. The third approach to allocation builds on the second because the poverty reduction impact for each commodity depends on the number of people involved, and the share of them who are poor and able to be boosted out of poverty by the innovation under consideration. The results suggest that, for Rwanda at least, allocation of resources based on the much more visible output share (or congruence) method may provide almost as large a gain relative to uniform allocation as the poverty-reduction share approach.

Value Chain Innovations

Governments have important roles to play in value chain innovations as well as in agricultural research and development. The role of government in these areas is quite different in that there is rarely the same type of market failure as encountered in agricultural R&D. In most cases, marketing institutions are able to undertake more of their own research than farmers. Frequently, innovations are also embedded in machines, where the developer of the equipment has an incentive to innovate because of patent protection provided on the good, or in designs readily available from the work of past innovators.

Government innovations in the value chain frequently include:

(i) Provision of infrastructure,

(ii) Setting of standards

(iii) Enforcement of contracts,

(iv) Maintaining effective competition, and

(v) Provision of market information.

These four interventions are critical and are like agricultural research and development in that they will likely be severely under-provided by individual participants in markets. Governments—especially in developing countries—frequently become involved in the provision of market infrastructure, such as regional and terminal markets for agricultural products. Less frequently, and with a distinctly more limited record of success, governments become directly involved in marketing activities such as transport, processing and storage. Where possible, it is usually best for governments to focus on providing the enabling environment and encouraging private sector agents to undertake marketing activities.

As previously noted, Rwandan agriculture currently uses very small amounts of intermediate inputs. This may change, as farms become more commercially-oriented, but at this stage, a small reduction in costs on inputs that account for only a small share of the value of gross output will likely provide relatively little benefit to farmers. Improvements in transport infrastructure that lower the cost of inputs may encourage their use and ultimately encourage development of an agricultural sector with greater use of intermediate inputs and higher productivity. But at this stage, with the current structure of Rwandan agriculture, the gains from lowering input costs are likely to be relatively small.

On the downstream side, the situation is quite different. The Rwanda Input-Output table suggests that processing activities use very large amounts of non-agricultural inputs and factors relative to the value of raw agricultural inputs that they purchase. This suggests that lowering these costs could substantially increase the net prices payable to farmers and/or reduce the cost to consumers of processed agricultural products. Several features of their input-output structure are quite striking. The first is the relatively small share of agricultural raw materials (including outputs from other firms in this processing sector) in their intermediate inputs. Cereals, for example, account for only 20.3 percent of the total output value of the cereal processing sector. Only for Bakery products and traditional beverages are these shares much above 30 percent. For the important processing sectors for meat, fish and dairy products, and cereals, the share of non-agricultural intermediate inputs are 61 and 57 percent, with commercial services most important in meat, fish and dairy, and transport services for cereals. The small share of labor in the total cost structure of these commodities means that improving productivity in these relatively small sectors is likely to generate relatively small gains in wages, leaving most of the gains to arise through reductions in the gap between producer and consumer prices.

Table 8. Input shares in gross output of the agricultural processing sectors, % of Gross Output

	Meat, Fish, Dairy %	Cereals %	Coffee %	Tea %	Bakery %	Traditional Beverages %
Agric Intermediates	21.0	20.3	28.9	31.4	60.7	78.8
Nonagric Inter	62.9	57.5	20.4	20.8	11.2	4.4
Labor	7.6	11.9	18.5	18.3	14.0	8.9
Capital	8.4	10.3	32.2	29.5	14.1	7.8
Total	100	100	100	100	100	100

Source: Pradesha and Diao (2014).

Rwanda has undertaken some major reforms for coffee, designed both to reduce costs and to enhance the quality of the product. These reforms are expected to contribute substantially to improving farm returns and export revenues from coffee (Macchiavello and Morjaria 2013). The substantial costs evident in cereals and livestock products suggest that the poverty reduction impact from reducing costs and raising quality for those products are also likely to be very high. With other costs four times the value of the farm products entering these value chains, the potential for gains is particularly large. The potential for improvements in consumer welfare from improved quality of consumer products is also likely to be substantial—as has previously been observed with coffee washing in Rwanda.

Conclusions and Policy Implications

This study has examined the potential for Rwanda's agricultural sector to contribute to policy reduction either by allocating more resources to agricultural R&D and/or by reallocating resources between crops. Rwanda has made considerable progress in improving agricultural productivity and in reducing poverty, but much more needs to be done to increase the dynamism of the economy and the rate of poverty reduction.

From the available evidence on the links between R&D investment and productivity growth, it seems likely that Rwanda could increase agricultural productivity substantially by raising the share of agricultural GDP devoted to R&D from its current low level of 0.44 percent. Increasing agricultural R&D closer to 1 percent of GDP could perhaps increase agricultural productivity in the order of 50 percent. Such an increase in productivity could, in turn, reduce poverty at the US $1.90 per day level endorsed as a target by the African Union.

Based on a range of different approaches, it seems likely that such a large gain in agricultural productivity could reduce the poverty headcount rate from its current 51 percent to below 40 percent. The extent of the poverty reduction achieved would, however, depend on the way research resources were allocated across commodities. We find that allocations of research resources based on the value of farm output or on poverty reduction impacts would result in roughly twice as high as under a uniform allocation.

While the returns in terms of poverty reduction from value chain interventions that reduce marketing costs depend very much on the specific interventions undertaken, the very large marketing costs currently incurred in the production of cereals, meat, fish and dairy products suggest that the impacts of interventions that reduce these costs and improve product quality are likely to be large.

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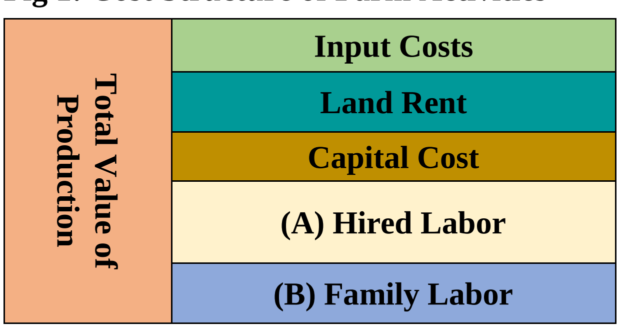
Appendix

Preparation of Household Data

For the household modeling undertaken in this study, we need to prepare a balanced data set that incorporates of the financial flows in which each household is involved. On the income side, households finance their purchases from: (i) agricultural activities, (ii) other business activities, (iii) wages, and (iv) other financial flows, such as transfers, remittances and the accumulation or decumulation of assets. On the expenditure side, we focus on household spending on agricultural goods and a composite of all other consumption goods.

Obtaining the balanced data set we need on the production side is challenging because the household survey data are incomplete in some important ways. The data on household agricultural activities include estimates of the value of output for individual crop and livestock activities, use of intermediate inputs in production, the quantity (but not the value) of household labor used on farm, purchases of hired labor and the quantity and value of household-member labor sold off-farm by activity type. As is typical with such household surveys, there is no decomposition of returns to agricultural or non-agricultural activities into returns to capital, land and labor. There are also challenges in that intermediate input use in agriculture exceeds gross agricultural returns for around 10 percent of households. In this study we have undertaken several modification or data treatment in the household survey data Rwanda, with a two-fold goals: (i) properly valuing the total labor supply owned by the households is allocated through a constant elasticity of transformation to the farm and non-farm activity and (ii) building the proper cost structure for the farm activity.

Fig 1: Cost Structure of Farm Activities

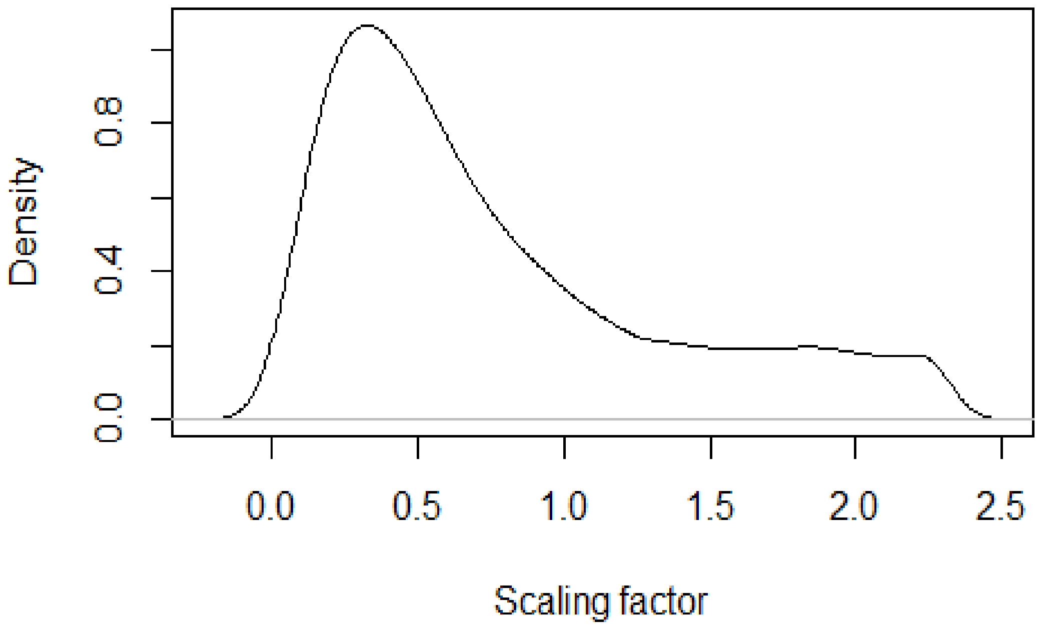


(A) + (B) = total labor costs in the farm (traditional cost structure)

Our first step in obtaining a complete representation of the production structure was to add estimates of the returns to agricultural capital and land as a share of gross farm income to the accounts. We then estimated the return to operator and family labor by applying the average hourly wage received in each district by households selling labor to agricultural activities to the hours of labor that family members used on their own farm. We assumed that household labor on farm earned the same amount per hour on and off farm. Finally, we needed the values for returns to capital and land and for this we preserved the value of gross output and the ratios between farm output value and capital and land. From the IFPRI Social Accounting Matrix (Pradesha and Diao 2014; Golan, Judge and Robinson 1994) we find the land and capital share in gross output of agricultural activities excluding forestry were 35.02% and 9.04% respectively.

In this way, we created a complete vector of costs for each household with farm business activity, albeit one that did not necessarily add up to the reported gross value of farm output. Our intention was to use a technique such as cross-entropy to adjust these so that they both added up to gross output value and, on average, broadly matched the allocation between factor returns and intermediate input costs in the 2011 SAM. As a first step towards this, we scaled all other elements of the tentative cost structure matrix for each household by the common multiplicative factor needed for that household's agricultural income to equal its outlays on returns to intermediate goods and factors. Because all our scaling was multiplicative, we didn't have to introduce a shadow tax or subsidy to make up the residual and ensure zero-profit production in each sector. The distribution of the scaling factors used is shown in Figure 3. The mean value of this scaling factor is slightly higher than 0.75 and the plot reveals a number of worryingly large scaling factors above 2.0.

Figure A.1. Density plot of the scaling factor used to ensure zero profits in each sector



Following this step, we found that the average share of expenditures on factors was very close to the share indicated by the Social Accounting Matrix and we ceased the iterative procedure. This also addressed the negative business profit cases. Moreover, the procedure zeroed all costs where households didn't report any output. As Table A.1 below reveals, total factor shares (weighted) end up at 87% of gross output, which is quite close to what we got from the Social Accounting Matrix – 89%. The land and capital shares were reduced to 28.3% and 7.3% respectively. Input costs account for 12.7 percent of gross output value.

Table A1: Shares of factors and intermediates in gross farm output

By input types	**Share (%)**
Factors (all)	87.3
Intermediate input	12.7
Factors	
Household Labor	48.4

Table A1: Shares of factors and intermediates in gross farm output

Hired labor	3.3
Capital	7.3
Land	28.3
Intermediate Inputs	
Seed	2.9
Fertilizer	1.4
Hand tools and other equipment	1.6
Packing and storage	0.2
Transport	0.2
Pesticides, insecticides	0.3
Irrigation	0.0
Animals, feed and delivery	4.0
Veterinary services	0.5
Others	1.6

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