Working paper

International Growth Centre

Evaluating the impacts of agricultural productivity growth on poverty

A methodology for analysis in Rwanda

Will Martin

Febraury 2016

DIRECTED BY

FUNDED BY

Evaluating the Impacts of Agricultural Productivity Growth on Poverty: A Methodology for Analysis in Rwanda

Will Martin

International Food Policy Research Institute

19 February 2016

Evaluating the Impacts of Agricultural Productivity Growth on Poverty: A Methodology for Analysis in Rwanda

Assessing the impacts of productivity growth on poverty involves a number of steps. The purpose of this short paper is to lay out the steps involved as a basis for making such an evaluation in a small economy such as Rwanda. This impact occurs through several channels, and capturing it requires that we take into account, in particular: (i) the direct impacts of productivity growth on those farmers who choose to adopt a higher-productivity approach to production; (ii) the impacts of higher productivity on the prices of food paid by the poor and the near-poor, and (iii) the impacts of higher productivity on the factor prices, and particularly the wages received for unskilled labor.

Clearly, any analysis of the implications of productivity change must take into account a combination of changes at the individual farm level—such as the impacts of changes in productivity on farm output and the revenues from production. But, particularly in a small economy such as Rwanda, the analysis must take into account economy-wide impacts such as the impacts on food prices and on factor prices paid to low-income workers. To do this requires a combination of economy-wide modeling and detailed household analysis. The purpose of this paper is to explore ways in which this might be done in a rigorous way, guided by the available data and modeling approaches.

The first section of the paper provides some key background material. In particular, it reviews reasons offered in the literature for why we might expect productivity growth in agriculture to generate larger gains in poverty reduction than productivity growth in other sectors. The second section lays out a methodology that might be used to carry out such an evaluation, given essential information on the structure of the economy and on the income sources and expenditure patterns of households.

Why Productivity Growth in Agriculture Matters for the Poor

A large body of research has demonstrated that the impacts of economic growth on poverty reduction depend heavily upon the sector in which the growth occurs. In particular, many studies (such as Ravallion & Datt, 1996) have demonstrated that growth in rural areas may be associated with much more rapid reduction in poverty than economic growth in urban areas. Loayza and Raddatz (2010) highlight the potential importance of the labor intensity of the sectors in which productivity increases (e.g. agriculture, construction and services) in determining the rate of poverty reduction, and find that rapid productivity growth in these labor-intensive sectors has a greater favorable impact on poverty reduction than the same rate of productivity growth in other sectors. Other studies have noted that agricultural growth may have particularly important impacts by reducing the cost of food to poor consumers in closed economies (or in relatively isolated economies such as Rwanda). This argument applies also to very widely adopted innovations that result in lower world food prices (see Dercon, 2009).

A number of recent studies, by contrast, have concluded conclude that the role of growth in the non-agricultural sector in poverty reduction is increasing (eg Christiaensen, Demery and Kuhl (2011) and Himanshu, Lanjouw, Murgai and Stern (2013)). This raises important questions about whether agriculture retains its traditionally critical importance for poverty reduction in countries where agriculture is now a smaller share of the employment and the economy. Of course, agriculture retains an extremely important share of employment (75%) and GDP (33%)

in Rwanda and so improving agricultural productivity is likely to have a larger impact on poverty than in economies where it has declined to a smaller share of employment.

The existing literature on the poverty impacts of higher agricultural productivity growth is suggestive the higher agricultural productivity growth in Rwanda might play a particularly important role in reducing poverty. However, it does not provide clear-cut evidence that agriculture would be quite so effective in reducing poverty in Rwanda. Further, the available evidence does not provide any guidance on practical policy questions confronting policy makers on agricultural research in Rwanda. In particular, it provides only very general advice on the particular sub-sectors or commodities in which productivity growth might have the greatest impact on poverty.

Much of the work that has demonstrated the linkages between the sectoral composition of growth and poverty reduction outcomes has used econometric approaches. This approach has important advantages because it allows hypotheses to be tested against real-world data. It also allows possible alternative channels of effect to those originally hypothesized to be assessed and compared. Ravallion and Datt (1996), for example, found using econometric approaches that movement between sectors was less important for poverty reduction than growth rates within sectors.

Econometric approaches, however, face many challenges. The rate of output growth in each sector is clearly strongly endogenous, depending upon factors such as productivity growth rates, and yet it is common to use the output growth rate as an explanatory variable. It would seem desirable to use the rate of productivity growth as an explanatory variable and yet measures of this variable are difficult to obtain and rarely used as explanatory variables. Even where productivity growth measures are available, they are likely to suffer, like measures of output, from endogeneity problems that may bias estimates of their impacts on poverty reduction. While creative approaches to reducing endogeneity bias are available and are typically used, the effectiveness of these approaches is uncertain.

An Approach to Measuring the Impact of Productivity Growth on Poverty

The approach proposed in this paper is to use a Computable General Equilibrium (CGE) model developed for Rwanda linked to detailed models for 14,000 households for Rwanda. This approach is based on rigorous use of economic theory and data on the structure of the economy and on patterns—and potential patterns--of international trade. The key parameters used—such as the elasticities of substitution between factor inputs, elasticities of consumer demand, and Armington elasticities of substitution between domestic and imported goods from different sources—are based on econometric estimates where these are available and on surveys of the econometric literature where estimates for Rwanda are not available. For many of the questions that we consider—such as the impacts of changes in productivity or prices—the key determinants of our results are actually the shares of expenditure on different goods, and the shares of income from different sources, rather than these behavioral parameters.

Because we are using simulation models, we are able to consider the impacts of pure changes in productivity—and potentially different types of productivity growth—when assessing the impacts on poverty. One of our objectives is to assess whether simulation models can capture some of the key stylized results arising from econometric models in particular cases. While one must always be aware of the potential limitations of using a simulation approach when the true structure generating the outcomes of interest is unknown, Kehoe (2005) concluded that simulation models can do a good job when modeling shocks such as the implications of changes in productivity. If we find that simulation modeling gives similar results to econometric modeling in the cases where the two can be compared, we can use the simulation approach to assess the impacts of different types of productivity growth, or productivity growth in different contexts, and to infer implications for poverty at a global level.

We believe that results from simulation models are potentially very strongly complementary with those from econometric models. Where results are available from both and are broadly comparable, we can increase our confidence in our accumulated knowledge. In this case, the ability of the simulation framework to extend the analysis to different cases, such as when the productivity change is global provides valuable additional insights. Where the results from simulation and econometric studies are not consistent, then further analysis is needed to try to understand the differences. As we will see, simulation analysis can also provide important insights into the parameters that need to be identified and estimated in future econometric analyses.

The first step in the causal chain from productivity to poverty is the nature of the productivity growth considered. Uniform productivity growth[1] in all sectors is a special case and we consider scenarios in which productivity grows only in agriculture, in industry, and in services. Many different types of productivity growth might be considered, including productivity growth that augments different factors to different extents;[2] productivity growth that saves on intermediate inputs as well as on factors. Productivity growth may also be specific to

[1] For many purposes, it is useful to distinguish between improvements in technology and changes in the efficiency of firms relative to the technological frontier. We treat productivity growth from either source as equivalent in this discussion, although the differences between the two approaches will be explored in the study.

[2] The special case of labor-augmenting technical changes is widely used in macroeconomic models because it yields a balanced growth path. However, sectoral productivity growth may also augment land or capital, and growth paths may be far from balanced over substantial periods.

particular regions (this is frequently especially obvious in agriculture) or to particular types of firms. In this initial analysis, we focus on changes that augment all factors equally. This lets us identify differences in poverty impacts that result from the two channels of effect identified in the literature—those resulting from differences in impacts on the earnings of the poor and their cost of living.

Changes in productivity affect low-income households in three basic ways: (i) through changes in the productivity of the factors they employ in businesses, such as farms or service enterprises, that they operate; (ii) through changes in the prices of goods and services that they consume; and (iii) through changes in the factor returns (and particularly wages) that they receive from the factors they sell outside their owned businesses.

If we focus on the case where productivity gains reduce the quantity of each factor used in a particular sector or, equivalently, increase the output attainable with a given factor bundle, the impact on profitability and output can usefully be represented using a distinction between actual and effective outputs (see Martin & Alston, 1997 for a more detailed discussion). 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 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 $p^* = p\tau$. For expositional purposes, it is useful to obtain a second-order approximation to any production technology using 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 a particular sector.

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

(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 1 about here >>

As shown in Figure 1, the productivity change has two effects on output at any given actual price. The first effect is an increase in output at any given input level. It increases output in the positive quadrant, and hence corresponds to the move from S_1 to S_2 in Figure 1.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 changes the output (or input demand at points to the left of the vertical axis) 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 1) 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 a first-order impact on welfare 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. This distinction makes it very important to distinguish, in econometric work designed to estimate the impact of a particular innovation, between the two sources of 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

We recognize that the exposition of technical change in terms of output bias is a very specific formulation, and that productivity growth in agriculture may take many other forms, such as changes biased towards saving particular inputs discussed in Bustos, Caprettini and Ponticelli (2013). However, the same distinctions between the direct effect of productivity change and the profitability-induced changes in output or input are likely to be important in analyses of different types of technical change.

Where sectors are large, increases in productivity may change factor and commodity prices, which may have important impacts on the welfare of households and hence, potentially, on poverty. To capture these impacts, we need to take into account changes in all of the prices facing poor and near-poor producers. In addition, we need to take into account impacts on their costs of living. The procedures for this are discussed in the next section.

Methodology

The complexity of the task requires that we employ several distinct methodological steps in sequence. In the first step, we employ a model of Rwanda (Diao et al 2010) to identify the long-run implications of a set of productivity shocks for national income, and for product and factor prices. In the second step, we apply the productivity and price shocks to the 14,000 household-level models which we use to simulate the welfare, and hence the poverty, implications of the productivity shocks considered.

The General Equilibrium model

We plan to use the Rwanda model (Diao et al 2014) to estimate all of the economy-wide implications of productivity gains of different types in particular sectors. A key advantage of this model over more generic models such as the GTAP model (the Africa database for which includes Rwanda) is that its classification of sectors is specifically tailored to Rwanda. It identifies all of the major agricultural sectors in Rwanda, including maize, rice, sorghum, wheat, Irish potatoes, sweet potatoes, bananas, pulses, coffee and tea.

We plan to assume an unchanging level of unemployment in each region and allow wage rates to adjust in response to changes in supply and demand. In this mode, an increase in productivity in any one sector with output prices constant will likely draw resources away from other sectors because of the increase in profitability in the sector experiencing higher productivity. If output prices fall, consumers will benefit from lower living costs and other sectors will benefit from lower prices of goods used as intermediate inputs.

Because of high transport costs, increases in exports of many commodities seem likely to require substantial reductions in prices. This effectively makes these commodities nontradable and has profound implications for the implications of productivity shocks for commodity prices, and hence for household welfare. Increases in productivity of some importable commodities might similarly result in substantial price declines (with benefits to consumers and losses to consumers) once domestic production completely replaces imports.

The Rwanda model will provide a set of changes of factor and goods prices along with estimates of effective producer output prices. Changes in effective prices for value added are converted into changes in effective output prices for the household supply models, while the expenditure modules in these models use actual prices.

The household models

A money measure of household welfare W at a given utility level, u,is given by:

$$\boldsymbol{W} = \boldsymbol{\pi}(\boldsymbol{p}^{*}, w, \boldsymbol{\tau}) - \boldsymbol{e}(\boldsymbol{p}, w, \boldsymbol{u}), \quad (4)$$

Where $\pi(\boldsymbol{p}^{*}, w, \tau)$ is a profit function representing the profits generated by any unincorporated household enterprise, such as a farm firm, specified as a function of effective commodity prices, factor prices and technology; $e(\boldsymbol{p}, \mathrm{w}, u)$ is a full cost function of the type used by Deaton and Muellbauer (1981) for a household that consumes goods and supplies factors at a given vector of commodity prices, p, factor prices, $\boldsymbol{w}$, and utility level, u. Note that the actual prices of goods and factors are generally endogenous in the macro modelling stage but are always exogenous at the household level.

The right side of equation (4) may usefully be rewritten as $\boldsymbol{z}(\boldsymbol{p}, w, \tau, u)$. With this simplification, a second-order approximation of the welfare impact of changes in $\boldsymbol{p}$, w and τ may be compactly written as:

$$\Delta \mathrm{W} = \left[z_p z_w \pi_\tau\right] \begin{bmatrix} \Delta \boldsymbol{p} \\ \Delta w \\ \Delta \tau \end{bmatrix} + \frac{1}{2} [\Delta \boldsymbol{p} \quad \Delta w \quad \Delta \tau] \begin{bmatrix} z_{pp} & z_{pw} & \pi_{p\tau} \\ z_{wp} & z_{ww} & \pi_{\mathrm{w}\tau} \\ \pi_{\tau \mathrm{p}} & \pi_{\tau \mathrm{w}} & \pi_{\tau\tau} \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{p} \\ \Delta w \\ \Delta \tau \end{bmatrix}, \quad (5)$$

This quadratic form takes into account both the quadratic relationship between technological change variables and output levels in equation (3) and the impacts of endogenous changes in quantities resulting from price changes and considered in Ivanic and Martin (2014). The first term in (5) includes the net sales of the household times the change in the price of the commodity, $z_p \Delta \boldsymbol{p}$, the measure of welfare change emphasized by Deaton (1989) for analysis of commodity price changes. It also takes into account the impact of changes in factor prices, and especially wage rates, times the net sales of the household outside its unincorporated enterprises such as farms, service or industrial enterprises , $z_w \Delta w$. Finally, it takes into account the direct impact of changes in technology on the profits generated by household firms given a change in technology, $\pi_\tau \Delta\tau$. As shown in Ivanic and Martin (2014), the second-order terms generalize these first-order impacts taking into account the induced changes in the output of household enterprises and changes in sales of labor when changes in technology and any resulting changes in prices are large.

Given our focus on productivity change, it is important to examine the direct impact of productivity change on the profits of the farm firm in more detail than the other elements of this quadratic form, which are discussed in Ivanic and Martin (2014). The π_τ term for an individual good is readily seen to equal $\frac{d\pi}{dp^*}\frac{dp^*}{d\tau} = p.q^*$. The $\pi_{\tau\tau}$ term then equals $p.\frac{dq^*}{dp^*}.p$. Converting these into more familiar proportional change form yields an intuitive expression for the second-order impact of a single technological change on household real income at constant nominal prices as:

$$\frac{\Delta\pi}{\pi} = \left[\frac{p_i^* q_i^*}{\pi}\right].\frac{\Delta\tau_i}{\tau_i} + \frac{1}{2}\sum_j \left[\frac{p_j^* q_j^*}{\pi}\right]\eta_{ji}\left(\frac{\Delta\tau_i}{\tau_i}\right)^2$$

where η is the price elasticity of supply and all other terms are as previously defined. As shown in the discussion of Figure 1, this welfare effect consists of a first-order effect that depends only on the initial level of output, and a second-order impact that depends on the price responsiveness of output to price. As is evident from equation (5), valuation of equation (5) requires estimates of the price responsiveness of household demands for consumption goods and of the output supply and input demand responses of household firms.

Once the estimated changes in real income for each household have been obtained, we count—by applying the available household weights—all households which move across the poverty line—defined at 1.90 USD/person/day or 3.10 USD/person/day—and calculate the corresponding change in the poverty headcount. This provides us with estimates of the impacts on poverty for different types of productivity increase.

Representation of household demand responses

We plan to use the Constant Difference of Elasticities (CDE) specification to characterize consumer demand (Hertel, 1997). For consistency with the macro analysis, we use the estimated CDE substitution parameters from the GTAP model, together with each household's expenditure shares, to calculate its own- and cross-price elasticities of demand. Following Hanoch (1975), we define a matrix of compensated elasticities ϵ for CDE preferences as:

$$\varepsilon_{i,j} = (\alpha_i + \alpha_j - s^T\alpha)s_j - \frac{\alpha_i}{s_i}\Big|_{i=j}$$

Where the $\alpha_i s$ are the CDE substitution parameters and s is a vector of consumption expenditure shares.

The values of s for each household will be obtained directly from the household survey data by calculating its consumption shares for each commodity. Because the expenditure shares vary by household, the matrix of elasticities is specific to each household.

Representation of household firm input/output elasticities

Production of each good in the household firm model will be represented by a two-level nested CES production function. In the bottom nest, the household firm combines its factors according to a Constant Elasticity of Substitution (CES) production function and then combines this value-added composite with material inputs using another CES production function to define total output. We make the default assumption that the CES elasticity between value added and intermediate inputs is zero, so that intermediate inputs are used in fixed proportion to output.

Zero-profit conditions for each activity ensure that the price received for each output equals the cost of its production and define the supply price for each output. Household firms that produce multiple types of outputs are able to shift their factors between outputs with the same restrictions on factor mobility as are imposed on the national model. They are also able to transfer labor between household business activities and outside activities depending upon the returns available within the farm firm and outside.

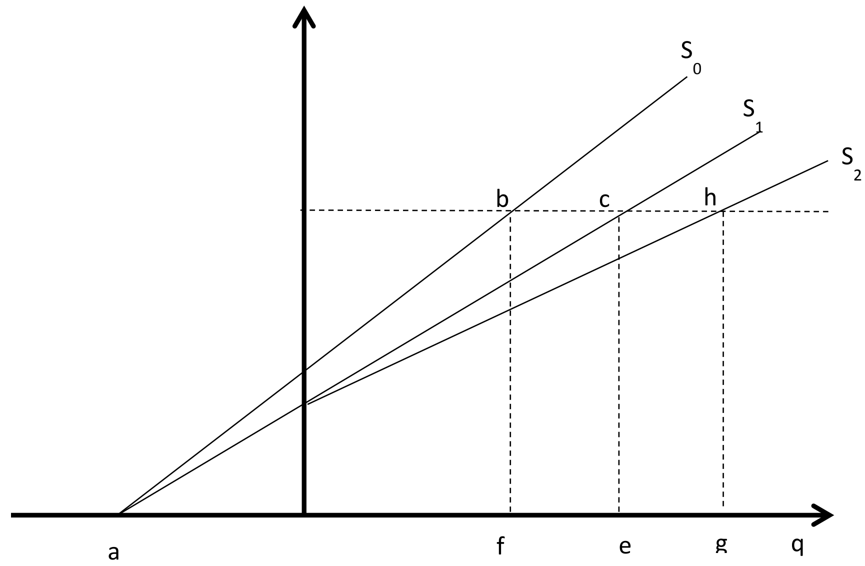
For each household firm, we will calculate a set of long-run output supply and input demand parameters based on a simple Heckscher-Ohlin model: in this long-run closure all factors except land and natural resources are assumed to be perfectly mobile. Land can be moved between activities, but not without cost given differences in the attributes of particular parcels of land, a situation which is represented very simply using an elasticity of transformation of one. Because the initial input and output mix of each household is different, the elasticities of supply at the household level vary depending upon the range of products they produce. If, for instance, the share of rice in the output of a household is large, the household's elasticities of supply for rice will be relatively low. These elasticities are given in Ivanic and Martin (2014).

Conclusions

The approach outlined in this paper is designed to provide a rigorous approach for evaluating the implications of agricultural productivity growth on poverty in Rwanda. It is designed to build on the high quality work that has been done at IFPRI to develop a detailed model of the Rwandan economy, and the thorough household surveys that provide information on household income and expenditure patterns in Rwanda. The challenge to which this analysis is addressed is to use these inputs to make a rigorous analysis of the implications of productivity growth in agriculture in Rwanda.

The purpose of this analysis is to lay out an approach by which a rigorous assessment of the implications of productivity growth on the poor might be made. This framework is intended to provide guidance on the areas in which improvements in productivity might have the greatest gains in terms of poverty reduction. Once the modeling approach has been developed, it can be used to explore a wide range of potential approaches to productivity improvement both in agriculture and in related sectors such as processing.

Figure 1. Impacts of an increase in productivity



References

Bustos, P., Caprettini, B. and Ponticelli, J. (2013), 'Agricultural productivity and structural transformation: evidence from Brazil, NBER Conference, July 24-5. http://conference.nber.org/confer/2014/SI2014/DEV/DEVprg.html

Christiaensen, L., Demery, L. and Kuhl, J. 2011. 'The (evolving) role of agriculture in poverty reduction—An empirical perspective' *Journal of Development Economics* 96:239–54

Deaton, A. and Muellbauer, J. (1981). 'Functional forms for labor supply and commodity demands with and without quantity restrictions' *Econometrica*, 49(6):1521–32.

Dercon, S. 2009. 'Rural poverty: old challenges in new contexts' *World Bank Research Observer,* 24(1), 1–28.

Diao, X. Fan, S., Kanyarukiga, S. Yu, B. (2010), *Agricultural Growth and Investment Options for Poverty Reduction in Rwanda*, IFPRI Research Monograph, International Food Policy Research Institute, Washington DC.

Deaton, A. 1989. 'Rice Prices and Income Distribution in Thailand: A Non-Parametric Analysis' *The Economic Journal* 99(395): 1–37.

Hanoch, G. 1975. 'Production and Demand Models with Direct or Indirect Implicit Additivity'*Econometrica* 43(1):395–419.

Hertel, T. 1997. *Global Trade Analysis*. Cambridge: Cambridge University Press.

Himanshu, Lanjouw, P, Murgai,R. and Stern, N. 2013.'Nonfarm diversification, poverty, economic mobility, and income inequality: a case study in village India *Agricultural Economics* 44:461–73.

Ivanic, M. and Martin, W. 2014. Short- and long-run impacts of food price changes on poverty, Policy Research Working Paper 7011, World Bank.

Kehoe, T. (2005). An Evaluation of the Performance of Applied General Equilibrium Models of the Impact of NAFTA. In T. Kehoe, T. N. Srinivasan & J. Whalley (Eds.), *Frontiers in*

Applied General Equilibrium Modeling: In Honor of Herbert Scarf (pp. 341–377): Cambridge University Press.

Loayza, N., & Raddatz, C. (2010). The composition of growth matters for poverty alleviation. *Journal of Development Economics,* 93:137–51.

Martin, W., & Alston, J. M. (1997). Producer surplus without apology? Evaluating Investments in R&D'. *Economic Record, 73*(221), 146–158.

Ravallion, M., & Datt, G. (1996). How important to India's poor is the sectoral composition of output. *World Bank Economic Review, 10*(1), 1–25

The International Growth Centre (IGC) aims to promote sustainable growth in developing countries by providing demand-led policy advice based on frontier research.

Find out more about
our work on our website
www.theigc.org

For media or communications
enquiries, please contact
mail@theigc.org

Subscribe to our newsletter
and topic updates
www.theigc.org/newsletter

Follow us on Twitter
@the_igc

Contact us
International Growth Centre,
London School of Economic
and Political Science,
Houghton Street,
London WC2A 2AE

International Growth Centre

DIRECTED BY

LSE

UNIVERSITY OF OXFORD

FUNDED BY

UKaid from the British people

Designed by soapbox.