The Nexus between
Agricultural Productivity, Poverty, and Social Services Provision
in Sub-Saharan Africa: An Empirical Analysis

Dissertation

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List of Abbreviations

2SLS	Two-stage least squares
AE	Adult equivalent
AIC	Akaike information criterion
BIC	Bayesian information criterion
CARA	Constant absolute-risk aversion
CFA	Franc de la Communauté Financière d'Afrique/West African CFA franc
CPI	Consumer price index
EICV	Enquête Intégrale sur les Conditions de Vie des Ménages au Rwanda
EMDAT	International Emergency Disasters Database
EPA	Enquête Permanente Agricole
EUROSTAT	The Statistical Office of the European Union
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agricultural Organization of the United Nations' statistical database
FE	Fixed-effects
FEP	Fixed-effects Poisson estimator
FEWS	Famine Early Warning Systems Network
FGLS	Feasible generalized least squares
GDP	Gross domestic product
GER	Gross enrolment ratio
GIC	Growth incidence curve
GMM	Generalized method of moments
GRIM	Growth rate in the mean
ha	Hectare
ICRG	International Country Risk Guide
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IFRC	International Federation of Red Cross and Red Crescent Societies
IFSP	Inverse farm size-productivity relationship
INSD	Institut National de La Statistique et de la Démographie au Burkina Faso
ISNAR	International Service for National Agricultural Research
IV	Instrumental variable
JMP	WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation
kg	Kilogram
MDGs	Millennium Development Goals
MINECOFIN	Rwandan Ministry of Finance and Economic Planning
NER	Net enrolment ratio
NIGIC	Non-income growth incidence curve
NISR	Rwandan National Institute for Statistics
OC	Opportunity curve
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary least squares
OPM	Oxford Policy Management

p.c.	Per capita
PGIC	Productivity growth incidence curve
PNGT	Deuxième Programme National de Gestion des Terroirs
POC	Productivity opportunity curve
PPCH	Pro-poor change
PPG	Pro-poor growth
PPGR	Pro-poor growth rate
PPP	Purchasing power parities
PRIO	Peace Research Institute Oslo
PRS	Political Risk Services
PWT	Penn World Tables
R&D	Research and development
RE	Random-effects
RWF	Rwandan Franc
SSA	Sub-Saharan Africa
TFP	Total factor productivity
TLU	Tropical livestock units
UIS	UNESCO Institute for Statistics
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WASAT	West African Semi-arid Tropics
WDI	World Development Indicators
WHO	World Health Organization

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Introduction

"Agriculture alone will not be enough to massively reduce poverty, but it has proven to be uniquely powerful for that task."

World Development Report 2008 (p. 1)

According to the Human Development Report 2014, approximately 842 million individuals worldwide suffer from chronic hunger and around 1.2 billion people live below the international poverty line of $1.25 a day (UNDP 2014). From these two numbers alone, it is obvious that – despite major successes over the last two decades – poverty reduction will continue to be one of the most important challenges for humanity in the 21st century.

A common and straightforward way to approach the task of poverty reduction is to ask two basic questions: *who are the poor* and *where do they live*? Starting with the second question, one can use numbers from PovCalNet, the World Bank's online poverty analysis tool (World Bank 2014), to illustrate the regional pattern of poverty. Applying the $1.25 international poverty line[1], poverty is in absolute terms mainly concentrated in three regions: South Asia (approximately 507 million poor individuals), Sub-Saharan Africa (414 million), and East Asia and the Pacific (251 million). However, this picture changes considerably when pursuing a relative approach such as the poverty headcount ratio. Accordingly, poverty incidence is relatively highest in Sub-Saharan Africa with approximately 48 percent of the population living on less than $1.25 a day followed by South Asia (31 percent) and East Asia and the Pacific (12 percent). Looking at time trends for this indicator further reveals that while all three regions started from relatively similar levels in the year 1990[2], East Asia and the Pacific as well as South Asia were considerably more successful in reducing the poverty headcount ratio (declines of roughly 44 and 23 percentage points, respectively), while it decreased only slightly in Sub-Saharan Africa (by approximately 8 percentage points). Thus, one can expect that the challenge of fighting extreme poverty will mainly be centered in South Asia and Sub-Saharan Africa over the next few decades.

Apart from the distribution among world regions, recent research pointed out that roughly three out of four poor people live in rural areas[3] and that the depth of poverty is typically greater in

[1] All numbers correspond to the year 2010 (the most recent data available) and rely on 2005 purchasing power parities (PPP).
[2] More specifically, the 1990 values were 56.24 percent for East Asia and the Pacific, 53.81 percent for South Asia, and 56.53 percent for Sub-Saharan Africa (World Bank 2014).
[3] It should be noted that Ravallion et al. (2007) used in their calculations still the old international poverty line of $1.08. Yet, it can be expected that the overall pattern would be very similar if the $1.25 international poverty line was used.

pastoral surroundings (Ravallion et al. 2007; World Bank 2007). While there seems to be a trend towards an urbanization of global poverty with the poor urbanizing faster than the non-poor (Ravallion 2002; Ravallion et al. 2007), extreme poverty is set to remain a predominantly rural phenomenon for decades to come (World Bank 2007). This observation brings us back to the first question, namely *who are the poor*?

In attempts to answer this question, researchers have identified a number of characteristics that poor individuals in developing countries regularly share (e.g. Alderman et al. 2000, Ames et al. 2000, Eastwood and Lipton 2000, Ravallion and Datt 2002). Klasen (2004) summarized these findings by stating that the poor typically depend either directly or indirectly on agriculture, own mainly the production factor of semi- or unskilled labor and sometimes land while the endowment with human capital is rather limited. In the same vein, a recent poverty profile by the World Bank estimates that around two thirds of the global poor are working in the agricultural sector, typically as smallholder farmers (World Bank 2013a).

Taking the above-described characteristics together, it can be deducted that, at least in the short-term, the agricultural sector will have to play a key role in the fight against poverty. In fact, one could even expect that growth in the agricultural sector will have a higher poverty elasticity than economic growth overall since it is more likely to make use of the assets of the poor (Klasen 2004). This question has been tested empirically by Loayza and Raddatz (2010) who found the sectoral composition of economic growth to be important for poverty reduction. More specifically, the authors detected that unskilled labor-intensive sectors (e.g. agriculture, construction and manufacturing) bear the greatest potential and agriculture even stood out as the most poverty-reducing sector. In addition, de Janvry and Sadoulet (2010) estimated that GDP growth originating in agriculture leads to income growth for the poorest 40 percent of the population that is around three times larger than growth originating in other sectors of the economy. This result is partly driven by the direct poverty reduction effect of agriculture, but also by agriculture's strong links with other economic sectors. Finding a similar comparative advantage of agriculture for poverty reduction, Christiaensen et al. (2011) conclude that agriculture reduces poverty among the poorest of the poor significantly more effectively, yet this advantage declines as the poor target group becomes richer.

Based on the above-described research findings another question directly arises: *If agricultural growth is that successful in reducing extreme poverty, how can it be stimulated*? One could start to address this question by pointing out that there are essentially two possible ways of increasing gross agricultural output – either by expanding the cultivated land area or by increasing agricultural land productivity. However, with regard to the former, the room for improvement starts to become increasingly scarce in various low- and middle-income countries (e.g. some Northern and Central African states) while there still seems to be considerable potential for productivity improvements in virtually all developing countries. More specifically, the Food and Agriculture Organization of the United Nations (FAO) estimates that to feed the expected world population of 9.1 billion in 2050, overall food production will have to rise by approximately 70 percent[4] (FAO 2009). Of this increase, approximately 90 percent is expected to stem from higher yields and increased cropping intensity while the contribution of land expansion is most likely limited to just ten percent. Indeed, these shares are slightly different for developing countries alone, still it has to be expected that at most 20 percent of the required growth in crop production in low-income countries will come from a rise in the cultivated land area (FAO 2009). Taken together, the above figures underline the need to increase agricultural productivity levels – not only to ensure global food security – but also to stimulate agricultural growth and ultimately poverty reduction in developing countries.

To achieve this goal, considerable investments in the agricultural sector will be required which has recently been emphasized in FAO's annual flagship report *The State of Food and Agriculture* (FAO 2012). The agricultural capital stock per worker has, however, remained constant or even declined over the last three decades in two of the world's poorest regions, namely South Asia and Sub-Saharan Africa (FAO 2012).[5] Clearly, this finding is to a great extent driven by high population growth rates in these two regions, but nevertheless underlines the urgent need for further capital investment in the agricultural sector. One could thus be tempted to infer that developing countries' governments should try to channel as much of their scarce resources as possible into the agricultural sector in order to increase agricultural productivity levels. However, such an approach would bear *at least* three major drawbacks.

First, as reflected in a large number of dual economy models (e.g. Lewis 1954; Ranis and Fei 1961; Kuznets 1966) and regularly confirmed by empirical research, agriculture must rather be considered a low-productivity sector and a country's development will typically be driven by industrialization. As a consequence, the importance of the agricultural sector in terms of employment as well as its contribution to GDP will decline as countries get richer. The implied structural change thus puts developing countries' governments in the difficult situation of having to increase investment in agriculture while at the same time being forced to spend additional

[4] The reference period for this estimate is 2005 - 2050 (FAO 2009).
[5] According to FAO (2012), the average annual change in the agricultural capital stock per worker was -0.1 and -0.6 percent for South Asia and Sub-Saharan Africa, respectively.

money on other sectors to promote their development. This challenge is potentially most acute in Sub-Saharan Africa where agriculture's share in total employment still amounts to close to 80 percent in a number of countries (McMillan and Headey 2014).

Second, by far the largest source of agricultural investment in low- and middle-income countries is private on-farm investment which is almost four times as high as government investment (FAO 2012). Against this background, it is debatable whether governments will be able to widely increase agricultural productivity levels directly or whether the main challenge is rather to create an attractive investment climate which enables smallholders and large-scale investors alike to increase investment in a sustainable manner (FAO 2012). From a poverty perspective, it will be particularly important to allow smallholders to overcome existing barriers to savings and investment which regularly constitute poverty traps, particularly for the poorest households (Rosenzweig and Wolpin 1993; Fafchamps and Pender 1997). Such interventions may often take the form of public goods that the private sector alone would not provide such as agricultural research, education and rural infrastructure. This is also the kind of public investment that recent empirical studies found to be the most effective in triggering agricultural growth and poverty reduction (Fan and Zhang 2008).

Third, developing countries' governments often act under strong pressure to satisfy the acute social needs of the growing population in terms of the provision of health care, education, and social safety nets. Such pressure is not surprising given that according to recent data from the World Development Indicators (WDI 2014), the life expectancy at birth in low-income countries is still only approximately 62 years and under-5 mortality amounts to approximately 82 out of 1,000 live births. Similarly, only about three out of five adult persons are able to read and write and net enrolment rates, particularly for secondary education, are, despite considerable increases over the last decade, very low (approximately 44 percent). However, the provision of such services for a growing population has the downside of engrossing considerable financial resources which are hence unavailable for investment in productive sectors such as agriculture.

This last argument illustrates that policy-makers in developing countries often face the difficult task of having to balance the population's current interests in terms of access to social services against productive investments in the agricultural sector which may enhance household incomes in the near future. Studying this trade-off and potential synergies was the underlying motivation for a collaborative research project by the International Food Policy Research Institute in Washington DC and Dakar, the University of Ouagadougou (Burkina Faso), the Rwandan National University, the Sokoine University (Tanzania) as well as the University of Göttingen.

The following dissertation is in part a product of this research project and contains one cross-country analysis and two country case studies for two of the project countries (namely, Burkina Faso and Rwanda). One unifying feature of all three essays is that they are all located at the interface of agricultural economics and development economics which appears straightforward given the above-mentioned importance of the agricultural sector for poverty reduction. In the following paragraphs each of the three essays is briefly summarized.

Essay 1: Revisiting the Role of Education for Agricultural Productivity

From a micro perspective, the role of education for agricultural productivity is rather unambiguous. The vast majority of studies find that educated farmers exhibit higher levels of agricultural productivity than their uneducated counterparts even after controlling for a variety of potentially important covariates. With regard to underlying mechanisms, the literature focuses mainly on four transmission channels. First, education is supposed to let farmers become better "managers" by enhancing their decision-making skills (Asadullah and Rahman 2009). Second, education improves the peasant's access to information and therefore allows him/her to potentially pay and receive better prices for the inputs used and the outputs sold (Jamison and Lau 1982). Third, various empirical studies have shown that better educated farmers adopt promising new technologies on average faster and therefore have a first mover advantage (Feder, Just, and Zilberman 1985; Hossain et al. 1990; Lin 1991; Asfaw and Admassie 2004; Weir and Knight 2004). Lastly, it is regularly argued that as a consequence of the improved decision-making skills, better educated peasants generally prefer riskier production technologies (typically promising higher returns) since they are able to evaluate adequately the implied opportunities and risks (Asadullah and Rahman 2009).

The above-described evidence from the micro-level stands in sharp contrast to recent cross-country studies applying sophisticated econometric methods which either have not included education variables at all in the model (e.g. Frisvold and Ingram 1995) or have only been able to detect insignificant (Vollrath 2007) or even puzzling negative coefficients for the education variables used (Craig, Pardey, and Roseboom 1997). Given this micro-macro paradox, in the **first essay** (co-authored by Stephan Klasen) the importance of education for agricultural productivity is revisited from the macro-perspective. We show that the failure to find a positive impact of education on the macro-level is actually a data problem related to the inappropriate use of enrolment and literacy indicators. Using a panel of 95 developing and emerging countries from 1961 to 2002 that includes data on educational attainment, we show that education indeed has a highly significant, positive effect on agricultural productivity which is robust to the use of different control variables, databases and econometric methods.

Distinguishing between different levels of education further reveals that only primary and secondary schooling attainment has a significant and positive impact while the effect of tertiary education is insignificant. In addition, the prominent argument claiming that education leads to higher agricultural productivity particularly in the presence of rapid technical progress (Nelson and Phelps 1966; Schultz 1975; Rosenzweig 1995; Foster and Rosenzweig 1996) is tested empirically in the cross-country framework. Support is found indicating that the returns to education (in terms of augmentations of the agricultural productivity) are higher for countries with higher levels of income.

Essay 2: Looking at Pro-Poor Growth from an Agricultural Perspective

The term of *pro-poor growth* was coined in the late 1990s/early 2000s to describe growth that allows the poor to benefit significantly from economic activity (Kakwani and Pernia 2000). While there has been a controversial debate about how exactly to define pro-poor growth beyond this very broad concept, there is a general consensus that pro-poor growth is actually one of the most promising pathways to achieve sustainable poverty reduction in the future (Klasen 2004). As a consequence, researchers have developed various instruments aiming to measure from an *ex-post* perspective the extent to which the poor benefited from recent developments in a country (sometimes referred to as the "pro-poor growth toolbox").

The **second essay** (co-authored by Stephan Klasen) is a methodological contribution to this literature which is motivated by the fact that existing research focuses too far on income and non-income dimensions of well-being. Given the above-mentioned extraordinary importance of agricultural productivity for poverty reduction worldwide, one reasonable way to further extend the concept is to examine how pro-poor productivity improvements have been. Therefore, we suggest in this essay that it is straightforward and useful to define the poor not only in terms of income, education or health, but also in terms of agricultural productivity. Such an approach can be readily implemented in the pro-poor growth toolbox by slightly modifying some of the existing tools and allows us to look at pro-poor growth from a complementary, agricultural productivity-based perspective.

To illustrate the potential of this extended toolbox, we then apply it to three waves of the nationally representative EICV[6] household surveys from Rwanda (years 1999-2001, 2005-2006, and 2010-2011), a country that faces the challenging situation of having to increase the productivity of the agricultural sector to ensure food security where land is an increasingly scarce factor which cannot be expanded much anymore. The results of our analysis indicate that Rwanda achieved in recent years impressive progress in both, income and non-income dimensions of poverty. The observed progress was in many cases not only pro-poor according to the weak-absolute, but also to the relative and in various cases even to the strong-absolute definition.

The new agricultural productivity-based tools, namely the monetary and crop-specific productivity growth incidence curves (PGICs), reveal that the labor productivity-poor were able to increase their productivity levels relatively (but not absolutely) faster than the productivity-rich. Using the productivity opportunity curves (POCs - Type 1), it is further found that the labor productivity-poor exhibit in all three surveys lower education levels than the labor productivity-rich. Yet, as part of the recent expansion of education in Rwanda the absolute gap in education between these two groups has decreased slightly over the last years. Lastly, the POCs (Type 2) reveal considerably lower labor and land productivity levels for human capital-poor households in Rwanda. This last finding is hence consistent with the main results from the cross-country analysis in the first essay which has highlighted the importance of education for agricultural productivity.

Essay 3: Livestock as an Imperfect Buffer Stock in Poorly Integrated Markets

The **third essay** (co-authored by Simon Lange) contributes to a long literature investigating poor households' ability to smooth consumption in the event of adverse income shocks. This topic is of great importance given that rural households are typically exposed to considerable risks (World Bank 2013b) and the need to hold precautionary savings has been found to generate poverty traps by preventing poor agents from undertaking profitable investments (e.g. Fafchamps and Pender 1997).

From a theoretical point of view, optimal savings theory predicts that, in the absence of formal insurance mechanisms and credit markets, households facing covariate risks will use liquid assets for self-insurance (e.g. Deaton 1990, 1991). In the West African context, the main form in which

[6] The French acronym EICV stands for Enquête Intégrale sur les Conditions de Vie des Ménages au Rwanda.

households may hold such extra savings are grain stocks and livestock and one would thus expect that these assets are consumed or sold in times of economic distress.

However, empirical studies investigating the role of livestock as a buffer stock remain inconclusive. Based on data from India and war-time Rwanda, Rosenzweig and Wolpin (1993) and Verpoorten (2009) find that households increase sales of livestock during droughts and episodes of civil conflict, respectively. In contrast, Fafchamps et al. (1998), Kazianga and Udry (2006), and Carter and Lybbert (2012) find – broadly speaking – no evidence that households are able to generate additional revenues via livestock sales based on data covering a drought in rural Burkina Faso in the 1980s.

This apparent puzzle has triggered a considerable debate in the *Journal of Development Economics* and we are trying to reconcile this literature. We emphasize that there are actually two strands of the literature pursuing slightly different questions. The literature around Rosenzweig and Wolpin (1993) and Verpoorten (2009) asks whether households increase the *quantities* of livestock sold in times of economic hardship and finds strong support for this hypothesis. This differs from the studies by Fafchamps et al. (1998), Kazianga and Udry (2006), and Carter and Lybbert (2012) which do not focus on *quantities,* but on *revenues* from livestock sales and are unable to find evidence for increased revenues.

To show that the results of both strands of the literature are by no means incompatible, we address in our empirical analysis both questions at the same time using two large panel household datasets which cover the 2004 drought in the northern provinces of Burkina Faso. Our results with regard to the first question suggest that livestock sales increase significantly in response to adverse rainfall shocks at the province- as well as the household-level and the need to purchase food is the main motive for such extra sales. In contrast, for the second question, we find that large parts of an adverse shock to transitory income are passed on to consumption while there is no evidence for additional revenues from livestock sales.

We then illustrate that declining livestock prices in poorly integrated markets may solve the puzzle if a drought-induced increase in the net number of animals sold is offset by a decrease in livestock prices. This renders adjustments to livestock holdings a costly strategy to smooth consumption. It also explains why households bear consumption cuts despite livestock holdings that would allow them to completely offset transitory income losses.

Policy Implications and Future Research

The above-described three essays should have direct implications for policy-makers in developing countries and also emphasize the need for further research. These issues are discussed below on a paper-by-paper basis.

The key message from the **first essay** is that formal education has a significant and sizeable effect on agricultural productivity not only at the household but also at the cross-country level. While mixed results from the previous literature provided policy-makers with rather little guidance on the benefits, in terms of agricultural productivity, of investments in rural education, our research was able to solve existing ambiguities. The detected effect is remarkable; not least since our results may actually underestimate the "full" impact of education on agricultural productivity. This is because educated individuals are more likely to seek work (either partially or fully) in the non-agricultural instead of the agricultural sector where the returns to their knowledge are potentially higher. Our results may hence be biased downwards since in our macro framework we are unable to adequately account for this endogeneity of activity choice by the farmers (e.g. Taylor and Yunez-Naude 2000). Thus, the detected robust positive coefficient of the schooling variable is comforting for policy-makers and underlines that investments in rural education not only enable farmers to leave the agricultural sector but have an additional desirable effect in terms of increased agricultural productivity levels. Our results further emphasize the complementarity of capital investments in the agricultural and the education sector since technical progress is needed to fully exploit the productivity-enhancing potential of schooling. This puts developing countries in the challenging situation of having to increase the population's access to education while at the same time increasing the capital intensity in the agricultural sector. This is certainly an area where the support by donor agencies and international organizations may make a significant contribution and thereby lessen the pressure on national governments.

With regard to future research, it should be stressed that due to a lack of adequate data, in our analysis we were unable to account for differences in the *quality* of schooling. This is highly unfortunate given that it can be expected that it is not just the *quantity* of schooling that matters for agricultural productivity. Hence, it would be very interesting to re-conduct a similar analysis once time series schooling quality indicators have become available for low-income countries.

Apart from introducing several new instruments into the pro-poor growth toolbox which are already relevant for policy-makers in their own right, the **second essay** emphasizes the need to look carefully not only at the distributional pattern of *development outcomes*, but also at the pattern of productivity growth as a *key driver of development outcomes*. To be aware of this difference is important for policy-makers in developing countries given that achieving pro-poor productivity improvements will increase the likelihood of reducing income inequality in the second step. Furthermore, the second essay emphasizes that at least in the Rwandan context, but likely also in other developing countries, land and labor productivity-poor households regularly exhibit quite different characteristics. This is interesting for policy-makers since both types of productivity-poor households are separate, but nevertheless equally important target groups in the pursuit of shared prosperity.

Future research should aim to shed further light on which interventions made the largest contribution to achieving the very positive overall picture in terms of productivity improvements that we observe in the pro-poor analysis. There we already mention some candidates that were promoted by the Rwandan government as part of *Rwanda's Vision 2020* such as the crop intensification programs, the commercialization of crops initiative as well as the erosion protection programs. However, the conducted pro-poor analysis can by definition not prove any kind of causality and it will hence remain for future research to quantify the contributions made by each single intervention. As a second step, it will then be important to analyze the external validity of such programs, i.e. to examine whether the interventions that worked well in the Rwandan context can also be applied to other Sub-Saharan African countries that are about to face a similar scarcity of agricultural land.

Besides solving an existing puzzle in the academic literature, the **third essay** underlines that the lack of market integration in rural Burkina Faso has severe negative consequences for Burkinabe farmers affected by adverse weather shocks. More specifically, it is found that households *did try* to use livestock as a buffer stock to smooth consumption, but this strategy was only successful to a limited extent. The underlying reason is that livestock prices declined considerably due to the covariate nature of adverse weather shocks rendering livestock an imperfect buffer stock. Given that settings with high risk of covariate weather shocks, limited access to credit and insurance and only imperfectly integrated livestock markets are ubiquitous in many developing countries, this paper has policy implications reaching considerably beyond Burkina Faso. First, the results call for an increased focus on integrating livestock markets (e.g. by investing in road infrastructure) that would help to reduce the volatility of livestock prices and thus mitigate welfare losses. Second, instead of relying on livestock as a buffer stock, another option for households is to hold grain stocks which have the additional benefit of being directly consumable thereby reducing households' dependency on potentially volatile market prices. However, grain stocks have the downside of being expensive as stocks exhibit limited durability and are often affected by pests (Binswanger and McIntire 1987). Hence, policy makers could aim to reduce the cost of this type of buffer stock by providing households with appropriate storage containers. Third, another potentially very promising avenue for reducing the vulnerability of rural households in developing countries lies in improving peasant's access to insect-resistant and drought-tolerant crop varieties. However, it is important to note that these interventions should be complemented by institutional and infrastructural improvements (Qaim 2011) and that they should ideally not incur any license fees for poor households. Lastly, appropriate insurance mechanisms should be put in place (e.g. rainfall insurance) that would allow households to stabilize incomes *ex-ante*.

Suggestions for future research are closely related to these policy implications. More specifically, it remains to be analyzed what is the most efficient way of improving market integration in remote rural areas and which role public-private partnerships can play in achieving this goal. In addition, various articles have pointed out that market-based provision of rainfall insurances in developing countries is far from an easy endeavor as most index-based insurance schemes suffer from very low uptake rates due to potential clients' lack of trust and a poor understanding of insurances more generally (Dercon et al. 2014). Hence, it will be for future research to find ways how these constraints can be overcome to ultimately increase demand for index-based rainfall insurances in the future.

1. Chapter

Revisiting the Role of Education for Agricultural Productivity[7]

with Stephan Klasen

This is a reprint of the article of the same name published in the
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Abstract

Various recent cross-country regressions have detected insignificant or even surprisingly negative effects of schooling on agricultural productivity. Applying advanced panel econometric techniques to a sample of 95 developing and emerging countries from 1961 to 2002, we show that these results are due to a problematic reliance on enrolment and literacy indicators. Using data on educational attainment, we instead find a sizeable and significant impact of schooling (avg. increase of approx. 3.2% per year of schooling) on agricultural productivity that is robust to estimation methods and model specification. We also find that returns from schooling are higher in technologically more advanced countries.

1.1 Introduction

Early studies on the determinants of agricultural productivity[8] across countries typically found significant positive coefficients for the education variables implying that higher levels of schooling lead to higher productivity (e.g. Hayami and Ruttan 1970; Nguyen 1979; Kawagoe,

[7] The authors would like to thank Summer Allen, Ousmane Badiane, Jacqueline Du Bois, Niels Kemper, Stefan Klonner, Sunday Odjo, Matin Qaim, Kimseyinga Savadogo, Matthias Schündeln, Susan Steiner, Michèle Tertilt, Maximo Torero, John Ulimwengu, Servaas van der Berg, Konstantin Wacker, Fleur Wouterse, two anonymous referees and Ed Taylor as the responsible editor for very helpful discussions and comments on earlier versions of this article. Furthermore, they are grateful to participants of workshops and conferences in Dakar, London, Heidelberg, Stellenbosch, and Bonn. This research is part of a collaboration between IFPRI and the University of Goettingen and is supported by the German Federal Ministry for Economic Cooperation and Development.

[8] The cited literature uses the term of agricultural productivity rather inconsistently to refer to either the (partial) productivity of land or labor (broadly defined as output per hectare and worker, respectively). In our analysis, we follow the example of the relatively recent articles by Frisvold and Ingram (1995) and Vollrath (2007) and will refer to the (partial) productivity of land when speaking of agricultural productivity. However, it should be noted that in our regression framework below, the two concepts are closely related. In fact, if one uses labor productivity as dependent variable and uses land per worker (and other conventional inputs likewise per worker) instead of workers per ha (as we do in the land productivity regressions) as an additional covariate, the coefficients for education are identical to the ones reported here for land productivity.

Hayami, and Ruttan 1985; Lau and Yotopoulos 1989[9]). However, these findings are contrary to the ones of some newer studies applying more sophisticated econometric methods which either did not include education variables at all in the model (e.g. Frisvold and Ingram 1995), or found insignificant (Vollrath 2007) or even puzzling negative coefficients for the education variables used (Craig, Pardey, and Roseboom 1997). Hence, the literature so far can be judged as rather inconclusive about the role of education for agricultural productivity in the international context.[10]

This is surprising given that the majority of micro studies find a significant positive effect for education (e.g. Ali and Flinn 1989; Young and Deng 1999; Alene and Manyong 2006). For example, Philips (1994, p. 149) even states that “there is a general consensus that education has a positive effect on agricultural productivity”. Regarding the mechanisms leading education to affect agricultural productivity, various arguments have been proposed and empirically tested in the literature. First, education is supposed to let farmers become better “managers” by enhancing their decision-making skills (Asadullah and Rahman 2009). Second, education improves the peasant’s access to information and therefore should allow him/her to potentially pay and receive better prices for the inputs used and the outputs sold (Jamison and Lau 1982). Third, various empirical studies have shown that better educated farmers are adopting promising new technologies on average faster and therefore have a first mover advantage (Feder, Just, and Zilberman 1985; Hossain et al. 1990; Lin 1991; Asfaw and Admassie 2004; Weir and Knight 2004). Lastly, it is regularly argued that as a consequence of the improved decision-making skills, better educated peasants are generally preferring riskier production technologies (typically promising higher returns) since they are able to evaluate adequately the implied opportunities and risks (Asadullah and Rahman 2009).

Given the preceding list of arguments supporting the view that rural education should enhance agricultural productivity, it remains an open question why cross-country studies using advanced econometric techniques were not able to find such an effect. In this article, we show that these studies fail to detect the expected impact because they are using inadequate variables (enrolment and literacy rates) to approximate the stock of education. Using a panel of 95 developing and emerging countries together with the newest version of the Barro-Lee educational attainment dataset (Barro and Lee 2010), we show that there is indeed a positive impact of educational attainment on agricultural productivity which is robust to changes in the control variables and in

[9] The article of Fulginiti and Perrin (1993) can also be counted to this literature even though its focus is rather on explaining changes in total factor productivity (TFP) than in the (partial) productivity of land or labor.
[10] There is a related but somewhat distinct debate on the role of education on income growth in developing countries. See, for example, Pritchett (2001).

the econometric methods applied. Furthermore, distinguishing between different levels of education reveals that only primary and secondary schooling attainments have significant positive impacts on agricultural productivity. In addition, the prominent argument claiming that education leads to higher agricultural productivity particularly in the presence of rapid technical progress (Nelson and Phelps 1966; Schultz 1975; Rosenzweig 1995; Foster and Rosenzweig 1996) is tested empirically in the cross-country framework. Support is found indicating that the returns to education (in terms of augmentations of the agricultural productivity) are higher for countries with higher levels of income. We not only show the effect of education using our data set, but are also able to show that the inclusion of our measure of educational attainment is robust to the use of data sets from other studies that previously had found no impact of education. Furthermore, we submit our results to extensive robustness checks and find very robust results in terms of magnitude and significance of effects.

The article proceeds as follows. Section 1.2 gives an overview of the literature on education and its effects on agricultural productivity. Section 1.3 describes the indicators previous cross-country studies have included in their regression to control for education and argues why the average years of schooling as obtained from Barro and Lee (2010) are a conceptually superior proxy. Section 1.4 provides a description of the methodological approach and the data used. In section 1.5, the results of the fixed and random effects as well as feasible generalized least squares (FGLS) models are discussed and some further extensions of the models are introduced. Section 1.6 shows the results of diverse robustness checks. Finally, in section 1.7, the main results are summarized and conclusions are drawn.

1.2 Schooling and agricultural productivity: mechanisms and micro evidence

Before starting to systematically review the existing literature dealing with the question why increased schooling could have a positive impact on agricultural productivity, it is necessary to discuss what is considered to be the effect of education in general. Nelson and Phelps (1966, p. 69) provide a widely-cited, relatively simple answer to this question by stating that education "enhances one's ability to receive, decode, and understand information". In addition, Schultz (1975, p. 835) argues that "education – even primary schooling – enhances the ability of students to perceive new classes of problems, to clarify such problems, and to learn ways of solving them". Welch (1970, p. 42) relates the effect of education to agricultural production and identified two distinct phenomena through which schooling can have a productive value, namely the "worker effect"[11] and the "allocative effect". According to him, the former describes the phenomenon that well educated workers are simply able to use a given amount of resources more efficiently. In contrast, the latter is characterized by the ability of an educated worker to sufficiently "acquire and decode information about costs and productive characteristics of other inputs" (Welch 1970, p. 42). As a result, the highly educated farmer will regularly use a different mix of inputs compared to a relatively low-skilled peasant, i.e. allocates resources more efficiently. This phenomenon can hence be called the "allocative effect". With regard to the relevance of these two effects for agriculture, there is nowadays a consensus among researchers that farmer's schooling generates its productive value mainly as a consequence of the allocative effect and only to a relatively limited extent from the worker effect (Huffman 1999).

Given that the concepts of the two above-described effects are still relatively vague, more recent literature has tried to further clarify the (often interrelated) transmission channels through which rural education may enhance agricultural productivity. However, it is important to emphasize that the basic notion of education as provided by Nelson and Phelps (1966) and Schultz (1975) is still relevant for these studies. The first argument commonly used to justify a potentially positive impact of education on agricultural productivity is a direct consequence of the above definitions. If one accepts that education allows farmers to make better use of the information available, to perceive new classes of problems and to autonomously find solutions to them, it directly follows that those peasants will possess superior decision-making skills and will hence be better "managers" allocating their resources more efficiently (Asadullah and Rahman 2009).

As a second argument, it is often claimed that well-educated farmers are not only capable of using available information more competently but also that they have better access to required information. Against the background that in many developing countries the majority of farmers have not received any schooling and are hence illiterate, it is easy to imagine that this lack of education is a severe obstacle for those peasants when seeking information. Thus, education provides peasants with the ability to disengage themselves from the "tight grip of […] inefficient 'word-of-mouth' communication patterns" (Welch 1970; Asfaw and Admassie 2004, p. 216). Taking this argument a step further, Jamison and Lau (1982) even argue that well educated farmers potentially pay and receive better prices for their inputs and outputs indicating that education can be a remedy to prevailing information asymmetries in the market.

[11] The phenomenon that Welch (1970) labeled as the "worker effect" is conceptually almost equivalent to what more recent studies typically describe with the term "technical efficiency" (Azhar 1991).

A third argument that has received considerable attention in the literature suggests that well-educated peasants are more likely to adopt new technologies or products early since they have superior access to related information and are better capable to distinguish between promising and unpromising innovations. In contrast, farmers with little schooling will often prefer not to introduce a new technology until its profitability has been proven e.g. until other farmers have successfully adopted the innovation (Nelson and Phelps 1966). This provides the educated farmer with a first-mover advantage making the new technology even more profitable and thus attractive for adoption. This argument is in line with the seminal contribution of Schultz (1975) who postulated that traditional agricultural societies are – in the absence of modernization – in an economic equilibrium since they have continuously optimized the use of the available resources over the generations. The occurrence of (exogenous) technological progress then pushes those societies away from the stationary state and allows them to achieve a superior equilibrium. However, the adjustment process takes time and its duration depends crucially on the population's ability to respond efficiently to the prevailing disequilibrium which can – according to Schultz (1975) – be enhanced through education. Consequently, the returns to education are expected to be higher in societies experiencing greater technical progress due to the henceforth increased level of complexity involved in the production process. On the contrary, in very traditional agricultural settings where tasks are rather simple, one would expect schooling to have only minor impacts on productivity (Schultz 1975; Schultz 1981; Rosenzweig 1995; Yang 1997). To the extent that income levels are correlated with levels and change of technology, this argument would suggest education to have a larger impact on agricultural productivity in richer countries.

In recent years, various authors empirically tested the above-described argument that educated farmers are more likely to adopt new technologies early and found overwhelming support for its validity (e.g. Feder, Just, and Zilberman 1985; Hossain et al. 1990; Lin 1991; Asfaw and Admassie 2004; Weir and Knight 2004). Most prominently, Foster and Rosenzweig (1996) analyzed data from the green-revolution period in India (specifically 1968-1981) and found increasing positive returns to schooling during this time of rapid technological progress. As an extension, they were even able to estimate the returns to schooling separately for areas faced with different levels of technological change.[12] The obtained results were in line with the above-described theoretical considerations from Schulz (1975) and a theoretical model provided by Rosenzweig (1995)

[12] This extension was possible since the contemplated Indian areas differed substantially with regard to (exogenous) weather and soil conditions and therefore did not have the same ability to exploit the new seeds profitably (Foster and Rosenzweig 1996, p. 932).

indicating that the returns to schooling increased significantly more in those areas where a high degree of technological progress took place.

In recent years, a fourth argument has emerged from the literature that is strongly linked to the previous one. It is claimed that educated farmers adopt new technologies earlier because they are more willing to adopt riskier production technologies if these technologies provide higher expected returns (Knight, Weir, and Woldehanna 2003; Asadullah and Rahman 2009). Hence, education is supposed to decrease the perceived level of uncertainty and therefore to reduce the farmer's aversion towards endogenous risk[13], i.e. risks arising from the peasant's choice of production technology. Knight, Weir, and Woldehanna (2003) tested this hypothesis empirically using household data from rural Ethiopia and found a significant reduction of risk aversion if the household head had received at least some schooling. This result implies that providing education to farmers not only lets them adopt *new* technologies earlier, but it may also change their attitude towards relatively risky *traditional* production technologies (e.g. crops they did not dare to plant before). As a consequence, the farmer may – after having received some schooling – optimize the mix of crops (including also riskier crops if they provide high expected returns) based on an improved ability to evaluate the associated risks and opportunities.

In contrast to the above-described four major arguments from the literature why increased education should have a positive effect on agricultural productivity, one could also think of theoretical reasons why studies find the returns to education to be small or even absent. First, it could – following an argument of Pritchett (2001) – be that the quality of education is just too low to effectively increase cognitive abilities and ultimately also productivity. Second, the skills provided in formal education may simply be too unspecific to positively affect agricultural productivity. However, this would immediately raise the question why most of the above-described micro studies were then able to find a productivity-enhancing effect of formal education. Third and probably most importantly, recent micro literature has emphasized that estimates of the agricultural productivity returns to schooling may potentially be biased downwards if the analysis does not adequately account for the endogeneity of activity choice by the farmers (e.g. Taylor and Yunez-Naude 2000; Yang and An 2002; Jolliffe 2004; Yang 2004). As – for instance – illustrated in a two-activity model by Taylor and Yunez-Naude (2000), it may be beneficial for rural households to allocate – at least parts of the – available investment resources (e.g. labor or land) away from crop production towards noncrop production if the marginal effect

[13] The literature typically subdivides risks into endogenous and exogenous ones (Knight, Weir, and Woldehanna 2003). While the former arises directly from the peasant's choice of technology (e.g. mix of crops), the farmer is not able to influence the latter risk which is thus exogenous to him (e.g. variability in rainfall).

of schooling on the net income-productivity of investments of the latter exceeds the one of the former. Applied to our case, this implies that we may potentially underestimate the total returns to schooling because we are limiting our analysis to the agricultural sector and will therefore not fully capture the returns to schooling of those educated individuals who decide to allocate – at least parts of their human capital – to sectors other than agriculture (where the returns to their knowledge are probably larger).

Besides the above-described literature on the relationship between overall education and agricultural productivity, various relatively recent studies have focused on particular aspects of this nexus. For instance, Asadullah and Rahman (2009) distinguished in their analysis between different levels of education obtained by rice producing households in Bangladesh. Their results show – not entirely surprisingly – that basic education (defined as primary and secondary schooling) is relatively more important for agricultural productivity than higher education. Other studies have focused on the question whether agricultural households are benefitting from externality effects. While the findings consistently affirm the existence of intra-household externalities (Yang 1997; Asfaw and Admassie 2004) implying that there is indeed a knowledge-spillover among different members of agricultural households (even when the educated person is not involved in farming activities), the evidence for extra-household externalities (meaning that better educated neighbors have a positive impact on a household's productivity) is rather ambiguous (Foster and Rosenzweig 1995; Knight, Weir, and Woldehanna 2003; Asadullah and Rahman 2009). Given the highly aggregated nature of our country-level data, it is not possible to test adequately for the existence of externalities. However, we will make efforts to distinguish between different levels of education in our analysis in section 1.5.

Clearly, the literature demonstrates a range of plausible mechanisms linking education to higher agricultural productivity and these mechanisms are often found to empirically play a role in micro studies.

1.3 Problems and issues with measuring education in macro studies

In the cross-country and panel literature on the determinants of agricultural productivity worldwide, there are in total four human capital measures which are regularly included in the production function to account for differences in the quality of labor. Out of these four, every author typically uses two indicators in each model: one is to allow for differences in farmers' health (either life expectancy at birth or total fertility rate) and one is to control for differentials in education (either adult literacy rate or gross/net enrolment ratio for primary/secondary education). Given the focus of this article, we will in the following only discuss the appropriateness of the two education measures.

Despite their widespread use in the literature (e.g. Hayami and Ruttan 1970; Nguyen 1979; Kawagoe, Hayami, and Ruttan 1985; Lau and Yotopoulos 1989; Fulginiti and Perrin 1993; Vollrath 2007[14]) both, gross and net enrolment ratios (GER and NER, respectively)[15], are rather inappropriate indicators for the current level of schooling of the working-age population in a country.[16] First, the data quality is often relatively poor since the enrolment rates are typically obtained from administrative records from schools which have a strong incentive to overstate the number of students in order to receive more resources for their institution. Second, the enrolment rates usually reflect the number of registered students at the beginning of the school year and thus do not take into account how many pupils drop out of class in the course of the year, i.e. they fail to adequately capture actual school attendance. Third and most importantly, enrolment ratios by definition just measure the *flow* of schooling and provide therefore information about the *future* and not the *current stock* of education in a country (Barro and Lee 1993). Only in the very particular case of stable enrolment rates for all countries, the GERs/NERs would be able to mirror the steady-state stock of education correctly. However, this assumption is rather implausible given the substantial but heterogeneous increases in developing countries' enrolment ratios in recent years (Schultz 1988; Pritchett 2001). Hence, enrolment ratios – gross or net – do not adequately reflect what the productivity literature wants them to reflect: the current stock of education available in a country.

As an alternative, the adult literacy rate, typically defined as the share of the population aged 15 and above having "the ability to read and write with understanding a simple statement related to one's daily life" (UNESCO 2011), has been used by various authors to approximate the population's level of schooling (e.g. Hayami and Ruttan 1970; Kawagoe, Hayami, and Ruttan 1985; Lau and Yotopoulos 1989; Craig, Pardey, and Roseboom 1997). This is not surprising given that the adult literacy rate possesses several features one would expect from a perfect measure for the level of education. First, the concept is relatively simple and the data are available for a wide array of countries. Second, the adult literacy rate indeed gives an idea of the current stock of education among adults in a country and is thus preferable to the enrolment ratios.

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14 Vollrath (2007) states in footnote 5 of his article that he tried to include primary enrolment ratios, but found them to be insignificant.

15 According to the UNESCO (2011), the NER is defined as the "enrolment of the official age group for a given level of education expressed as a percentage of the corresponding population" as opposed to the GER being defined as the "total enrolment in a specific level of education, regardless of age, expressed as a percentage of the eligible official school-age population corresponding to the same level of education in a given school year".

16 See also Barro and Lee (1993) for an extensive discussion of these issues.

However, there are also several drawbacks. Most importantly, the adult literacy rate must be judged as a relatively "crude measure of schooling" (Huffman 1999, p. 31) since it just refers to the "first stage in the path of human capital formation" (Barro and Lee 1993, p. 367) and does hence not sufficiently allow to assess the full extent of education. As a consequence, the adult literacy rate – if used as an indicator for the quality of labor in a productivity analysis – has the inherent problem that it implicitly assumes that any education higher than the most elementary level will not have any productive value (Barro and Lee 1993). Furthermore, it is by definition bounded above implying that it is not possible to achieve literacy rates higher than 100 per cent. Because of this feature, the variation between countries is artificially reduced, in particular when contemplating middle- or high-income countries. These last two drawbacks can, for instance, be exemplified with data for the Maldives and Israel. While the two countries are almost equal in terms of the adult literacy rate (97.0 and 97.1 per cent, respectively (UNDP 2009)), the average years of schooling differ substantially with a Maldivian adult having received on average 6.14 years of schooling compared to an average of 11.33 years for an Israeli (both numbers from Barro and Lee (2010)). This obvious discrepancy in the educational attainment in the two countries is not reflected sufficiently in the data and is thus ignored when taking the adult literacy rate to approximate the current stock of schooling.

Looking at the problems of the two schooling indicators from an econometric point of view, one can consider enrolment and literacy rates as variables that measure the true stock of education with error. As is well-known, measurement error leads to a downward bias in estimated coefficients which might explain the failure to find effects using these proxies.

In short, the two above-described measures both suffer from severe methodological weaknesses and do not adequately reflect the stock of education currently available in a country. Against this background, Barro and Lee (1993) introduced already in the early 1990s their educational attainment dataset which has since then been methodologically improved and regularly updated (Barro and Lee 1996, 2001, 2010). It is mostly based on reported school attainment data in census and household surveys (mainly compiled by UNESCO and EUROSTAT) which are then projected using robust simulation methods to generate the achievement data for the benchmark years. In particular, Barro and Lee (2010) calculate – as a first step – the educational attainment of the population by 5-year age groups and split then the distribution up into four rather broad attainment categories[17]. Forward and backward extrapolation is as a next step used to fill in missing observations with each group being assigned an age- and education-specific mortality rate

[17] Namely: No formal education, primary education, secondary education, and tertiary education.

(hence not assuming a uniform mortality). Nowadays, the variables from the dataset are widely accepted to provide the most reliable proxies for the stock of education for a large number of countries.[18]

For the analysis conducted in this article, we therefore decided to use the newest version of their dataset (Barro and Lee 2010), which offers 5-year-averages of educational attainment for 146 countries from 1950 to 2010. In particular, we will use the average number of years of schooling (s_t) for the population aged 15 and above which the two authors define as

$$s_t = \sum_{a=1}^{A} l_t^a \, s_t^a \qquad \text{with} \qquad s_t^a = \sum_j h_{j,t}^a \; Dur_{j,t}^{\,a} \tag{1.1}$$

where l_t^a denotes the share of age group a in the population aged 15 and above, s_t^a is the average number of years of schooling of age group a, h_j^a corresponds to the share of the age group a having attained the schooling level j = *primary, secondary, tertiary*, and *Dur* represents the duration in years corresponding to the respective level of education (Barro and Lee 2010, p. 7).

We argue that this indicator is methodologically superior to the measures previously used in the literature on the determinants of agricultural productivity worldwide because it shares the desirable characteristics of the adult literacy rate (relatively simple concept, good availability of data, actually measuring the *current* stock of education) and additionally has the advantage of not being restricted to the most basic level of education. Therefore, the variable accounts more adequately for the full depth of education.

However, it is important to emphasize that the Barro-Lee measures still do not meet two requirements that one would expect of the "perfect" measure of education in our particular context. First, the indicators are exclusively focused on the quantity of schooling received by the population and only partly account for quality differences. In particular, only to the extent that a student's achievements were insufficient to pass a grade will this be reflected in the educational attainment indicator which measures years passed (rather than years attended); quality differences beyond passing or failing a grade are not considered. Second, it would be highly desirable that the measure can be disaggregated into rural and urban areas since the vast majority of agricultural labor lives in rural areas. When testing the robustness of our results in section 1.6, we will make efforts to overcome this shortcoming. Despite these caveats, it is clearly the case that taking the average years of schooling as of Barro and Lee (2010) presents a crucial improvement to indicators previously used in the literature to approximate a country's stock of education.

[18] For example, UNDP recently replaced the adult literacy rate with the total years of schooling variable from Barro-Lee in the education component of the widely noted Human Development Index (UNDP, 2010).

From here onwards, the argumentation of this article is as follows. Based on the extensive theoretical considerations provided in section 1.2 as well as the empirical evidence found in two early meta-studies (Lockheed, Jamison, and Lau 1980; Phillips 1994[19]) and numerous micro studies (e.g. Ali and Flinn 1989; Young and Deng 1999; Alene and Manyong 2006) the hypothesis is that rural education indeed increases on average agricultural productivity. However, this stands in sharp contrast to recent cross-country studies applying modern econometric methods (particularly panel estimation techniques including time and country dummies) which either did not include any education variables in the model (e.g. Frisvold and Ingram 1995) or found insignificant (Vollrath 2007) or even puzzling negative coefficients for the education variables used (Craig, Pardey, and Roseboom 1997). Against the background of the above-described inadequacy of the education indicators used in those articles (adult literacy rate or gross/net enrolment ratio for primary/secondary education), we argue – in line with Huffman (1999, p. 31) – that the inability to detect the expected robust positive impact for education in the cross-country framework is rather due to data problems than due to the absence of real effects. This hypothesis will be tested in the following empirical part of the article using the newest version of the Barro-Lee educational attainment dataset, but using the same advanced econometric framework and covariates of the recent studies that had failed to find an effect.

1.4 Methodology and data

Our methodological approach is generally in line with the recent cross-country and panel literature on the determinants of agricultural productivity (e.g. Craig, Pardey, and Roseboom 1997; Vollrath 2007). We are assuming that the production process for the *i*th country at time *t* follows a common Cobb-Douglas production function. In particular, we estimate the following specification

$$lny_{it} = \alpha + \beta_x lnX_{it} + \beta_E E_{it} + \beta_V V_{it} + \beta_C C_i + \gamma_i + \delta_t + \varepsilon_{it} \qquad (1.2)$$

where the dependent variable is the natural logarithm of the output per ha and X_{it} is a vector of conventional agricultural inputs taken in per hectare terms. E_{it} is the above-described indicator for the average years of schooling as obtained from Barro and Lee (2010)[20]. Thus, β_E is the coefficient of main interest reflecting the partial productivity effect of education and it is expected to be positive. In addition, we also include V_{it} representing a vector of time-varying and

[19] However, the results of such meta-studies should always be regarded with the necessary caution since they implicitly assume that the methods and models of all contemplated studies were appropriate.
[20] Against the background that the average years of schooling are only available in five year intervals while all other variables in our model are disposable on an annual basis, we decided to linearly interpolate the schooling data.

C_i being a vector of time-invariant controls in the model (only when using random effects). Lastly, γ_i and δ_t, respectively, are country- and time-specific fixed effects typically included in panel models and ε_{it} is the potentially heteroskedastic error term. In some specifications, we also use random effects to reproduce other results from the literature and to be able to include C_i , our time-invariant country characteristics.

Following standard practice in this literature, we take the total value of all agricultural production after deductions for feed and seed (all expressed in 1999-2001 international $) divided by the total agricultural area in ha (both obtained from FAO statistical database (FAOSTAT)) as the dependent variable (see appendix A1 for the exact specifications and sources of all variables). The X_{it} vector contains four conventional inputs typically included in production functions, namely labor, fertilizer, tractors, and livestock (all in per hectare terms).[21] Data for the conventional inputs are all obtained from FAOSTAT whereat the livestock data is converted into cattle equivalents using weights from Hayami and Ruttan (1985)[22].

The vector of time-varying controls V_{it} can be subdivided into up to four categories. The first group of variables intends to account for differences in the quality of land. Therefore, we included the share of agricultural land equipped for irrigation and the percentage of agricultural land that is used as permanent meadows and pastures (both obtained from FAOSTAT) into our regression.[23] To further allow for differentials in climate, we additionally used satellite data reflecting the average precipitation on agricultural land in year *t* for country *i* (data from Williams and Breneman (2009)). As a second group of time-varying controls, two road traffic-related variables are used to make sure that the human capital variables not just capture the potentially positive effect of a well developed infrastructure. Typically, the literature uses for this purpose the road density defined as the total road length in km per 100 square kilometers of land area (data taken from Canning (1998) and WDI online, respectively). However, we argue that this concept is too narrow since it is rather not the pure disposability of roads that generates a productive value, but the effective ability of the economy to regularly use these roads. Therefore, we additionally try the per capita road sector energy consumption[24] (data from WDI online) to account for differentials in the infrastructure. Thirdly, it is important to rule out the possibility

[21] Land is not included as a separate input in the equation since constant returns to scale are assumed and the variable thus cancels out.

[22] Their widely-used weighting scheme allows to transform the headcounts of different animals into comparable units by assuming that 1 horse = 1 mule = 1 buffalo = 1.25 cattle = 1.25 asses = 0.9 camels = 5 pigs = 10 sheep = 10 goats = 100 chickens = 100 ducks = 100 geese = 100 turkeys.

[23] We also tried the land quality index of Peterson (1987) which is time-invariant and would thus belong to the vector C_i . However, it turned out that this variable greatly reduced our sample without adding any meaningful information.

[24] The correlation between the two measures is in our dataset approx. 0.45 implying that it is in fact possible to include both variables at the same time without introducing a multicollinearity problem.

that discrepancies in the quality of institutions are driving the results. To allow for this, we further include the political risk index taken from the International Country Risk Guide (ICRG) which is a commonly used indicator for a country's political stability (Political Risk Services 2005). The last category contains additional human capital variables not being included in E_{it}. In particular, two alternative measures are, in line with the literature, used to account for differences in the population's health level, namely the life expectancy at birth and the total fertility rate. In addition to the above-described time-varying controls, dummy variables for the legal origin as derived by La Porta et al. (1999) were included in the C_i vector of our model (only in the random effects specification) to allow for time-invariant differences in the legal system of the countries.[25] To give an overview on the data used for the analysis, table 1 presents summary statistics for the above-described variables.

Table 1: Summary statistics

Variable	Observations	Mean	SD	Min	Max
Net production per ha (intl. $)	3,282	271.87	296.28	2.68	2,063.74
Workers per 1,000 ha (number)	3,282	424.94	605.59	1.99	4,498.84
Tractors per 1,000 ha (number)	3,282	3.50	10.25	0.00	117.36
Livestock per 1,000 ha (in cow equivalents)	3,282	477.91	428.12	4.40	2,801.47
Fertilizer per 1,000 ha (in tons)	3,282	20.26	36.86	0.00	337.84
Irrigated land (in % of total)	3,282	6.26	10.10	0.00	67.12
Land in pasture (in % of total)	3,282	58.00	28.80	0.71	99.50
Precipitation on agricultural land (in mm)	2,184	1,164.65	701.55	6.00	3,738.00
Road density (km of roads per 100 sq. km of land)	1,654	17.24	24.32	0.26	220.13
Road sector energy consumption p. c. (kt of oil equivalent)	1,970	0.16	0.26	0.00	2.53
Life expectancy at birth (in years)	3,282	57.98	10.16	26.41	78.88
Total fertility rate (children per women)	3,273	5.16	1.80	1.09	8.73
Total years of schooling	3,282	4.40	2.52	0.04	10.80
Years of primary schooling	3,282	3.13	1.68	0.04	7.31
Years of secondary schooling	3,282	1.15	1.00	0.00	5.64
Years of tertiary schooling	3,282	0.12	0.15	0.00	1.07
Political Risk Index (ICRG)	1,288	56.34	12.30	14.08	81.67

A basic assumption that is standard in cross-country regressions trying to explain differences in agricultural productivity is that there exists a common production function which is applicable to all countries in the sample – a so-called "meta-production function" (Hayami and Ruttan 1970; Kawagoe, Hayami, and Ruttan 1985). Without any doubt, this assumption is strong and it can plausibly be argued that the agricultural production process differs between industrialized and

[25] According to La Porta et al. (1999), it is possible to classify a country's legal origin in one of the five following groups: English common law, French commercial code, German commercial code, Scandinavian commercial code, and Socialist/Communist law.

developing countries. Taking such objections seriously, the currently 34 OECD member countries were dropped from the dataset in order to reduce its heterogeneity, so that we are left with a sample of developing and emerging countries. In a robustness analysis below, we trim the sample further to reduce heterogeneity. We further excluded countries/territories with very small agricultural areas or labor forces to minimize measurement error since the corresponding data from FAOSTAT are generally rounded to thousands leading to a severe bias for countries having only small values for these variables.[26]

Finally, we also made efforts to clean our sample of all observations that are biased due to major natural disasters and/or armed conflicts. To account for the former, we divided for each year the number of inhabitants affected by earthquake, floods or droughts (obtained from EM-DAT (2011)) by the total population of the country. All observations where this ratio exceeded the threshold of one third were then excluded from the analysis since we consider an efficient agricultural production under these circumstances as practically impossible. In addition, we took battle deaths data from the Centre for the Study of Civil War (Lacina and Gleditsch 2005) and analogously calculated the share of the population that was killed in the specific year due to armed conflicts. We argue that a share of 0.1% (i.e. one in one thousand inhabitants) together with the associated flow of refugees is sufficient to impede efficient agricultural production. Hence, we dropped all corresponding observations from the dataset (see appendix A2 for a list of observations that were dropped due to the two exclusion criteria). As an alternative to dropping these observations, one could also include a dummy variable to account for natural disasters or armed conflicts. The results for this second alternative do not differ from the ones obtained when dropping the affected observations (see appendix A3).

The result of these modifications is a non-balanced panel covering 95 countries[27] for the time period from 1961 to 2002 (in most specifications our panel only reaches from 1976 to 2002 due to unavailability of data for some of the covariates for early years). Using a non-balanced panel for the estimation could generally cause the problem that the coefficients for different points in time may differ due to the fact that different samples are used. However, we do not see this as a major problem in our case for two reasons. First, all our regressions include country and year fixed effects which should capture the vast majority of the variation caused by changes in the

[26] Namely, the countries/territories dropped due to these two exclusion criteria are: American Samoa, Andorra, Anguilla, Aruba, Bahamas, Bahrain, Barbados, Bermuda, British Virgin Islands, Brunei, Cook Islands, Falkland Islands, Faroe Islands, French Guiana, Gibraltar, Greenland, Guadeloupe, Holy See, Kuwait, Liechtenstein, Luxembourg, Malta, Martinique, Monaco, Montserrat, Nauru, Netherlands Antilles, Niue, Norfolk Island, Northern Mariana Islands, Qatar, Palau, Saint Helena, Saint Kitts and Nevis, San Marino, Seychelles, Singapore, Tokelau, Turks and Caicos Islands, Tuvalu, United States Virgin Islands, Wallis and Futuna Islands.
[27] A detailed list of the countries and the number of observations is provided in appendix A4.

sample used. Second, it is not the goal of this article to compare the effect of education over time (in that case a non-balanced panel could severely bias the results), but to estimate the *average* effect of education on agricultural productivity.[28]

1.5 Regression results

As a first step of the analysis, two random-effect models (RE) are applied to the data (table 2). In the most basic specification (column 1), we include, besides the four conventional agricultural inputs (X_{it}), also the share of the agricultural land that is equipped for irrigation and the percentage used as permanent meadows and pastures. The coefficients of all variables are statistically significant and show the expected positive signs. The statistically significant negative coefficient for permanent meadows and pastures is also not surprising given that a high value for this indicator is typically a sign for a relatively low quality of the agricultural land which is presumably the reason for extensive land use as meadows and pastures.[29] We further include the ICRG political risk indicator (taken as an average for each country and assumed to be stable over time[30]) and the La Porta et al. (1999) legal origin dummies as two time-invariant country controls (C_i) as well as year dummies (δ_t). The political risk indicator has no significant impact while the legal origin dummy has a significant impact in one specification. Of course, the variables of main interest are those measuring human capital, namely life expectancy at birth and particularly the average years of schooling, which both show highly significant and positive coefficients. This implies that a higher level of education increases agricultural productivity which is in line with the theoretical considerations from section 1.2. The point estimate suggests that an additional year of schooling improves agricultural productivity by around 6 percent, a sizeable effect that is not only statistically but also economically significant.

It could still be argued that this finding is biased as no controls for differences in climate or infrastructure across countries were included in the model. However, as can be seen in column 2, this is apparently not the case since the inclusion of corresponding variables, i.e. the road sector energy consumption and the natural logarithm of average precipitation, does not materially

[28] To further test whether the use of a non-balanced panel affects our results, we re-estimated table 2 using a quasi-balanced panel (only including those countries in the sample where we have for the simplest specification data for at least 40 years). Even though this drastically reduced our sample, the coefficients for the average years of schooling variable remained in the preferred specifications highly significant and positive. This finding further increases our confidence that the use of a non-balanced panel is rather unproblematic in our case.

[29] This is consistent with the fact that the variable is highly negatively correlated ($\rho \approx$-0.75) with the land quality index from Peterson (1987).

[30] This assumption is in line with the literature (e.g. Vollrath 2007) and is in our case necessary since the political risk index is only available for the years 1984 onwards and we would thus lose all observations before this year. However, relaxing the assumption does not materially change our results (see robustness checks in table 6).

change the results for the schooling variable in terms of size and significance (due to unavailability of data for early years, the inclusion of these two covariates reduces our sample to the years 1976 to 2002[31]). Instead, this even increases its statistical significance to the 1% level and enhances the explanatory power of our model.

As a second step, we re-estimate the model using a fixed-effect specification (FE) with time dummies, thereby dropping the time-invariant controls (C_i). As can be seen in columns 3 and 4, using the fixed-effect instead of the random-effect specification does not materially change the results of our analysis. In particular, the coefficient of the schooling variable remains consistently positive, of similar size (5-6% return for a year of schooling) and highly significant. The Hausman specification test suggests that only the fixed-effect estimator is consistent and thus preferable.

[31] In addition, we estimated the specifications of columns 1, 3, and 5, using the reduced sample from 1976 to 2002 to investigate whether changes in the sample are responsible for changes in the estimated coefficients. However, results indicate that this is rather not the case.

Table 2: Results of the panel regressions

	(1) RE	(2) RE	(3) FE	(4) FE	(5) FGLS	(6) FGLS
(log) Livestock per ha	0.294***	0.291***	0.291***	0.293***	0.269***	0.291***
	(7.035)	(6.294)	(6.650)	(5.255)	(16.722)	(13.577)
(log) Fertilizer per ha	0.076***	0.056***	0.066***	0.060***	0.014***	0.017***
	(5.055)	(3.012)	(5.170)	(3.186)	(5.360)	(4.130)
(log) Tractors per ha	0.082***	0.095***	0.061***	0.076***	0.060***	0.063***
	(3.553)	(3.407)	(2.919)	(2.814)	(10.372)	(8.285)
(log) Workers per ha	0.162***	0.264***	0.106*	0.209***	0.177***	0.236***
	(2.830)	(4.281)	(1.738)	(2.766)	(8.023)	(8.067)
Area equipped for irrigation (%)	0.006**	0.004*	0.004*	0.004	0.005***	0.005***
	(2.264)	(1.918)	(1.691)	(1.579)	(5.493)	(4.650)
Permanent meadows and pastures (%)	-0.007**	-0.012***	-0.006*	-0.010***	-0.006***	-0.008***
	(-2.208)	(-4.557)	(-1.785)	(-2.670)	(-6.399)	(-7.068)
Life expectancy at birth	0.010**	0.013***	0.011***	0.012***	0.011***	0.011***
	(2.549)	(3.428)	(3.030)	(3.173)	(8.814)	(7.239)
Total years of schooling	0.060**	0.065***	0.053**	0.063**	0.033***	0.032***
	(2.442)	(2.991)	(2.020)	(2.512)	(4.325)	(3.542)
Road sector energy consumption		0.254**		0.226*		0.264***
		(2.302)		(1.838)		(3.615)
(log) Precipitation (mm)		0.035		0.027		0.021**
		(1.268)		(1.161)		(2.394)
Political risk index	-0.012	0.005				
	(-1.366)	(0.717)				
Dummy for French legal origin[a]	0.095	0.388***				
	(0.688)	(3.564)				
Dummy for Socialist legal origin	-0.004	-0.001				
	(-0.018)	(-0.007)				
Constant	6.789***	5.555***	5.843***	5.874***	5.405***	5.561***
	(12.044)	(12.369)	(20.720)	(14.498)	(44.843)	(37.108)
Observations	2,791	1,609	3,282	1,685	3,282	1,685
Number of countries	79	69	95	74	95	74
Country controls included	yes	yes	no	no	no	no
Time fixed effects	yes	yes	yes	yes	yes	yes
Country fixed effects	no	no	yes	yes	yes	yes
ε_{it} autocorrelation	none	none	none	none	AR(1)	AR(1)
Hausman test statistic[b]			175.09	68.57		
Hausman test p-value			0.00	0.00		
Wooldridge test statistic[c]			27.28	18.12		
Wooldridge test p-value			0.00	0.00		
Augm. Dickey-Fuller test statistic[d]	229.20	269.48	293.16	275.63	293.16	275.63
Augm. Dickey-Fuller test p-value	0.00	0.00	0.00	0.00	0.00	0.00
Phillips-Perron test statistic[d]	306.73	279.17	438.77	284.96	438.77	284.96
Phillips-Perron test p-value	0.00	0.00	0.00	0.00	0.00	0.00
R^2	0.891	0.936	0.840	0.912	n.a.	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level.

[a] The sample does not include any countries of German or Scandinavian legal origin; the left-out category is British legal origin.

[b] Hausman test statistic is distributed as X^2_{42} in column (3) and X^2_{30} in column (4).

[c] Wooldridge test statistic is distributed as F(1,94) in column (3) and F(1,73) in column (4).

[d] For the unit root tests, we applied the trend (due to a clear upward trend in avg. productivity worldwide) and the demean (to mitigate the potential impact of cross-sectional dependence) options. Choice of the lag structure was based on Akaike's and Schwarz's Bayesian Information Criteria (AIC and BIC, respectively) which uniformly recommended to apply an AR(1) structure for the tests. Test statistics are distributed as X^2_{158} in column (1), as X^2_{138} in column (2), as X^2_{190} in columns (3) and (5), and as X^2_{148} in columns (4) and (6).

The two estimation methods used so far do not control for serial correlation in the error terms. In line with Vollrath (2007), this assumption is questionable in the context of agricultural productivity analysis since various types of shocks are probably persistent over time (e.g. adverse weather conditions). To account for this possibility, the Wooldridge test for serial correlation (see Wooldridge 2002, p. 282) is applied and in both cases, the hypothesis of no first-order autocorrelation is strongly rejected. Hence, it is necessary to allow ε_{it} not only to be heteroskedastic (by calculating robust standard errors) but also to permit the error structure to follow an AR(1) process of the type $\varepsilon_{it} = c + \rho\varepsilon_{i,t-1} + \eta_{it}$ with ρ having a value between 0 and 1 and η_{it} being a white noise process with zero mean and variance σ_η^2. With regard to the parameter ρ there are generally two possibilities. On the one hand, it could be presumed that the errors follow a *unit-specific* first-order autoregressive process (thus using ρ_i instead of ρ in the equation). On the other hand, it is also possible to assume the parameter to be *homogenous* across countries (consequently using ρ). Beck and Katz (1995) convincingly showed using Monte Carlo simulations that the use of feasible generalized least squares (FGLS) under the assumption of a unit-specific ρ_i leads to severely underestimated standard errors, implying an extreme overconfidence in the coefficients, when T is not at least as large as N. Given that T in our dataset is considerably smaller than N (27 years compared to 95 countries), we decided to assume ρ to be homogenous across countries.

Hence, the two variants of the model are – as a third step – re-estimated using feasible generalized least squares methods with time and country dummies included in all specifications (columns 5 and 6). As can be seen, the FGLS results are generally in line with the ones obtained using the RE- and FE-models. However, the coefficients of some of the variables changed in magnitude and/or in statistical significance. Most notably, the t-value of the total years of schooling variable increases substantially when allowing for first-order auto-correlation while the absolute magnitude of the coefficient almost halves to 0.032 (column 6). Nevertheless, the impact of education on agricultural productivity is still sizeable implying that if each member of the population obtained an additional year of schooling, the agricultural productivity of the country would ceteris paribus increase by approx. 3.2%. To illustrate the economic relevance of the estimated effect, we also calculate the total contribution of the actually observed changes in the level of education to the observed changes in agricultural productivity. This is done by multiplying the total increase in the years of education between 1976 and 2002 with the estimated coefficient and dividing this product by the change in the log of the agricultural productivity between 1976 and 2002: $\frac{(6.48-3.55)\times 0.032}{(5.27-4.82)} \approx 20.84\%$. Using this approach, the change in the years of education accounted for more than 20% of the increase in agricultural productivity in the time period under investigation which is indeed a sizeable contribution.

To meet objections that we may have a spurious correlation problem since we neglect the time series properties of our data (given that our time dimension is relatively large, T=27 in our preferred model), we conduct unit root tests to check whether our dependent variable is a non-stationary series, that is, whether it is integrated of order one. The results of the Fisher tests (as proposed by Maddala and Wu (1999)) are unambiguous: both, the augmented Dickey-Fuller as well as the Phillips-Perron test, clearly reject the null hypothesis of an existing unit root (see table 2). Hence, spurious correlation should not influence inference in our case.[32]

As a next step, we try various extensions of our model (table 3).[33] First, we additionally include two variables regularly used in the literature, namely the total fertility rate and the road density (e.g. Craig, Pardey, and Roseboom 1997; Vollrath 2007). Both remain insignificant at all conventional levels while the coefficient of the average years of schooling remains relatively unaffected. Furthermore, the inclusion of these two additional controls greatly reduces our sample from 1,685 to only 737 observations. Consequently, we do not consider this extension as an improvement and therefore do not continue to include these two variables in our model. Second, we substitute our standard schooling variable by more disaggregated data reflecting the average years of schooling separately for primary, secondary and tertiary education (also obtained from Barro and Lee (2010)). The results indicate that the effect of an additional year of schooling conspicuously differs by type of education. In particular, we find in our preferred model (FGLS) the returns to primary and secondary education to be positive and statistically significant at the five per cent level whereas the effect of tertiary schooling on agricultural productivity is not significantly different from zero.

With regard to the magnitude of the coefficients, it is a bit surprising that the coefficient for secondary education exceeds the one of primary schooling. However, one explanation for this finding could be that it is not just the pure ability to read and write causing the greatest impact on agricultural productivity, but advanced analytical skills (not provided in primary schools) which become – as extensively discussed in section 1.2 – particularly important when adopting new

[32] Furthermore, we used the Pesaran CD test (Pesaran 2004) to check for cross-sectional dependence in the error terms. The test indicated that there is indeed some cross-sectional dependence which may potentially lead to underestimated standard errors. However, it turns out that the results of our analysis remain largely unchanged even when using the "correct" standard errors (following the widely-used approach of Driscoll and Kraay (1998)). To additionally investigate whether any structural breaks are present in our data, we conducted various graphical inspections, but were not able to find any indication for such breaks.

[33] Given that the Hausman specification test clearly negates consistency for all random effects estimations, we only show the FE and FGLS results whereat the FGLS estimates are preferable for the reasons discussed above.

technologies. This would provide further support for our approach of using years of schooling rather than adult literacy which captures much more basic education.

As a third extension, we use the GDP per capita (PPP) from the Penn World Tables 7.0 (Heston, Summers, and Aten 2011) to subdivide our sample into five income quintiles (with quintile 1 being the poorest and quintile 5 the richest).[34] We then generate dummy variables for each income quintile and multiply those with the average years of schooling indicator. This allows us to estimate the effect of an additional year of schooling separately for the five income groups while – at the same time – maintaining the assumption of a common meta-production function for all countries. The aim of this exercise is to empirically test the above-described hypothesis that the returns to education are generally higher in those societies that experience greater technical progress since the involved tasks in such settings become more complex and thus require a higher level of education (Schultz 1975; Rosenzweig 1995; Foster and Rosenzweig 1996), using GDP per capita levels as proxies for the level of agricultural technologies available to farmers.

[34] The easiest way to do such a classification would be to simply take either the initial or average GDP per capita for each country for the whole time period and rank the countries accordingly. However, this procedure has the drawback that all observations of a country are assigned to exactly the same group what makes the results of the analysis very sensitive to the allocation of countries to the income groups. Therefore, we decided to pursue a slightly different, but methodologically probably superior approach by first subdividing our sample into five-year intervals and then using for each of the intervals the GDP per capita in the first year to assign the observations belonging to that five-year interval to one of the income groups. This procedure is repeated for all intervals and has the great advantage of assigning the countries to income quintiles more flexibly, thus allowing the countries to switch the income quintile in the course of time. This is in our opinion the most appropriate way to account for the very differential growth performances worldwide (compare e.g. Southeast Asia with Sub-Saharan Africa) that have increased the farmer's access to technological innovations in some countries more rapidly than in others. One could suspect that we may create an endogeneity problem when ranking the countries according to their GDP while using the net agricultural productivity per ha as our dependent variable since these two measures may be highly correlated. However, the correlation between these indicators is in fact relatively low ($\rho \approx 0.22$). In addition, we argue that if there was a bias due to endogeneity, it would skew the estimates for the poorest quintiles downwards and not upwards as countries with rising agricultural productivity are more likely to leave this quintile.

Table 3: Extensions of the panel model

	(1) FE	(2) FGLS	(3) FE	(4) FGLS	(5) FE	(6) FGLS
(log) Livestock per ha	0.304***	0.220***	0.293***	0.290***	0.271***	0.266***
	(3.248)	(6.531)	(5.047)	(13.481)	(4.821)	(12.234)
(log) Fertilizer per ha	0.054**	0.015**	0.060***	0.016***	0.049**	0.012***
	(2.241)	(2.573)	(3.252)	(4.020)	(2.498)	(3.249)
(log) Tractors per ha	0.107**	0.088***	0.076***	0.064***	0.068***	0.061***
	(2.659)	(6.812)	(2.843)	(8.311)	(2.684)	(7.984)
(log) Workers per ha	0.074	0.220***	0.216**	0.236***	0.339***	0.281***
	(0.488)	(4.353)	(2.524)	(7.758)	(4.060)	(9.057)
Area equipped for irrigation (%)	0.002	0.006***	0.003	0.005***	0.004**	0.005***
	(0.621)	(3.296)	(1.537)	(4.548)	(2.058)	(4.907)
Permanent meadows and pastures (%)	-0.011	-0.013***	-0.010***	-0.008***	-0.009**	-0.006***
	(-1.570)	(-5.973)	(-2.698)	(-6.952)	(-2.368)	(-5.419)
Life expectancy at birth	0.013*	0.013***	0.012***	0.011***	0.010**	0.009***
	(1.879)	(4.020)	(3.101)	(7.222)	(2.157)	(6.235)
Total years of schooling	0.056*	0.048***				
	(1.755)	(3.251)				
Road sector energy consumption	0.302	0.310**	0.219*	0.272***	0.073	0.212**
	(1.556)	(2.532)	(1.841)	(3.705)	(0.197)	(2.427)
(log) Precipitation (mm)	0.031	0.024*	0.027	0.021**	0.025	0.023**
	(1.031)	(1.883)	(1.159)	(2.375)	(1.025)	(2.559)
Total fertility rate	-0.055	-0.000				
	(-1.228)	(-0.025)				
Road density	-0.001	0.000				
	(-0.997)	(0.951)				
Years of primary education			0.052	0.029**		
			(1.414)	(2.268)		
Years of secondary education			0.073	0.040**		
			(1.464)	(2.303)		
Years of tertiary education			0.110	-0.046		
			(0.432)	(-0.603)		
Income quintile 1 (poorest) * schooling					0.025	0.021**
					(1.062)	(2.269)
Income quintile 2 * schooling					0.039	0.028***
					(1.653)	(3.099)
Income quintile 3 * schooling					0.055**	0.035***
					(2.386)	(3.915)
Income quintile 4 * schooling					0.053**	0.032***
					(2.078)	(3.576)
Income quintile 5 (richest) * schooling					0.060**	0.032***
					(2.332)	(3.556)
Constant	6.191***	6.185***	5.908***	5.557***	6.165***	5.568***
	(10.021)	(15.759)	(13.702)	(36.370)	(14.351)	(37.583)
Observations	737	736	1,685	1,685	1,556	1,556
Number of countries	57	56	74	74	73	73
Time fixed effects	yes	yes	yes	yes	yes	yes
Country fixed effects	yes	yes	yes	yes	yes	yes
ε_{it} autocorrelation	none	AR(1)	none	AR(1)	none	AR(1)
Wooldridge test statistic[a]	8.97		18.12		15.28	
Wooldridge test p-value	0.00		0.00		0.00	
R^2	0.883	n.a.	0.913	n.a.	0.906	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level.

[a] Wooldridge test statistic is distributed as F(1,48) in column (1), as F(1,73) in column (3), and F(1,72) in column (5).

Our results (columns 5 and 6) generally confirm the predictions of the above-described hypothesis. In the fixed effects specification, the coefficient of education is statistically significant and positive only for the richest three quintiles while remaining statistically insignificant for the poorest two quintiles. In our preferred model (FGLS) the results are slightly different, indicating that the effect of an additional year of schooling is in fact highly significant and positive for all income quintiles. However, with regard to the magnitude of the coefficients, both models reveal a general trend of smaller coefficients for the schooling variable for poorer income quintiles. We interpret these results as support for the claim, already discussed in section 1.2, that in very traditional agricultural settings where tasks are typically rather simple, one would expect the returns to education to be smaller (Schultz 1975; Schultz 1981; Rosenzweig 1995; Yang 1997). To address the problem that per capita GDP might only be an imperfect proxy of the technological level, in a robustness check we show that using other proxies of the level of agricultural technologies from the literature does not materially affect the results.[35]

1.6 Robustness checks

As a first robustness check to our findings, we test in table 4 the question whether it would have been possible to find the above-described positive impact of education on agricultural productivity when using – instead of the average years of schooling from Barro and Lee (2010) – the measures typically used in the literature to approximate the current stock of education in a country (namely gross/net enrolment ratios and adult literacy rates).

While columns 1 and 2 reproduce our positive findings from table 2 (columns 4 and 6), the results change conspicuously when we simply substitute the total years of schooling with the gross enrolment ratio (GER) for primary education (columns 3 and 4) or the adult literacy rate[36] (columns 5 and 6). In particular, when using the GER as a proxy for the current stock of education, the FE-model indicates a highly significant, *negative* effect of education. In contrast, we find the coefficient not to be significantly different from zero in the FGLS model.[37] Similarly, when taking the adult literacy rate, the coefficient for education remains insignificant at all conventional levels in both models. Given our arguments in section 1.3 about the methodological

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[35] In particular, as alternative proxies for the level of agricultural technology, we followed the suggestion of Self and Grabowski (2007) and tried the fertilizer intensity (i.e. the amount of fertilizer used per hectare of agricultural land) as well as the interaction term of fertilizer intensity and tractor intensity (analogously defined as the number of tractors per hectare of agricultural land) to subdivide our sample into quintiles. It turned out that the corresponding results are very much in line with those using the GDP per capita as the grouping criterion (table 3), likewise indicating higher returns to schooling for technologically more advanced countries.

[36] Given that the available adult literacy data include many gaps, we decided to linearly interpolate the existing data.

[37] We also used the net enrolment ratio (NER) for primary schooling instead of the average years of schooling. The results are very similar to using GER and are shown in appendix A5.

weaknesses of these indicators, it is striking that the use of these indicators can actually impede the detection of the existing positive effect of education on agricultural productivity.[38]

Table 4: Robustness checks 1

	(1) FE	(2) FGLS	(3) FE	(4) FGLS	(5) FE	(6) FGLS
(log) Livestock per ha	0.293***	0.291***	0.341***	0.291***	0.316***	0.338***
	(5.255)	(13.577)	(5.252)	(13.652)	(4.498)	(14.053)
(log) Fertilizer per ha	0.060***	0.017***	0.062***	0.020***	0.062**	0.022***
	(3.186)	(4.130)	(3.422)	(4.754)	(2.551)	(4.344)
(log) Tractors per ha	0.076***	0.063***	0.059**	0.047***	0.053*	0.051***
	(2.814)	(8.285)	(2.147)	(5.677)	(1.822)	(6.873)
(log) Workers per ha	0.209***	0.236***	0.224***	0.261***	0.264**	0.254***
	(2.766)	(8.067)	(2.891)	(8.560)	(2.183)	(6.027)
Area equipped for irrigation (%)	0.004	0.005***	0.003	0.005***	0.004	0.003***
	(1.579)	(4.650)	(1.160)	(3.523)	(1.542)	(3.136)
Permanent meadows and pastures (%)	-0.010***	-0.008***	-0.011***	-0.008***	-0.010**	-0.007***
	(-2.670)	(-7.068)	(-2.926)	(-6.972)	(-2.135)	(-5.205)
Life expectancy at birth	0.012***	0.011***	0.013***	0.011***	0.010*	0.010***
	(3.173)	(7.239)	(2.973)	(6.829)	(1.925)	(6.197)
Road sector energy consumption	0.226*	0.264***	0.221	0.274***	0.181	0.180**
	(1.838)	(3.615)	(1.445)	(3.714)	(1.161)	(2.164)
(log) Precipitation (mm)	0.027	0.021**	0.012	0.022**	0.006	0.018**
	(1.161)	(2.394)	(0.585)	(2.552)	(0.255)	(1.963)
Total years of schooling	0.063**	0.032***				
	(2.512)	(3.542)				
Gross enrolment ratio			-0.002**	-0.000		
			(-2.495)	(-0.561)		
Adult literacy rate					0.003	0.001
					(0.735)	(1.261)
Constant	5.874***	5.561***	6.453***	4.661***	6.238***	5.742***
	(14.498)	(37.108)	(14.972)	(29.045)	(9.925)	(34.886)
Observations	1,685	1,685	1,575	1,574	1,321	1,313
Number of countries	74	74	85	84	84	76
Time fixed effects	yes	yes	yes	yes	yes	yes
Country fixed effects	yes	yes	yes	yes	yes	yes
ε_{it} autocorrelation	none	AR(1)	none	AR(1)	none	AR(1)
Wooldridge test statistic[a]	18.12		18.12		14.70	
Wooldridge test p-value	0.00		0.00		0.00	
R^2	0.912	n.a.	0.872	n.a.	0.894	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level.
[a] Wooldridge test statistic is distributed as F(1,73) in column (1), as F(1,82) in column (3), and F(1,72) in column (5).

Secondly, we want to test whether it would have been possible to find the above-described significant positive impact of education with datasets that previous authors have used to explain differences in agricultural productivity worldwide. Therefore, we took the dataset of Vollrath

[38] As a further robustness check, we also tested the empirical relevance of the variable share of the adult population with no schooling (also available in the Barro-Lee dataset). When we include it as an additional covariate, it hardly ever is significant and does not change the results on our preferred education indicator. When it is included instead of our preferred indicator, it has a negative and sometimes significant effect which is not very robust. Therefore, our preferred total years of schooling indicator is not only conceptually to be preferred but also empirically more robust.

(2007) and exactly replicated the panel results of his analysis (see table 5 columns 1 to 3 – corresponding to columns 4, 2 and 6 in table 6 in his article). We then re-estimated the model including the interpolated average years of schooling variable (everything else unchanged) which minimally reduced the sample due to the unavailability of education data.

Table 5: Robustness checks 2 (replication of Vollrath (2007)) [a]

	(1) RE	(2) FE	(3) FGLS	(4) RE	(5) FE	(6) FGLS	(7) FGLS
Gini coefficient	-0.49***	-0.50***	-0.48***	-0.51***	-0.49***	-0.07	-0.47***
	(-4.58)	(-4.22)	(-4.82)	(-4.72)	(-4.01)	(-0.80)	(-6.44)
Log avg. farm size	0.02	0.02	-0.06***	0.02	0.03	-0.03	-0.00
	(1.30)	(1.23)	(-2.88)	(1.28)	(1.50)	(-1.46)	(-0.27)
Inputs							
Log livestock per ha	0.41***	0.39***	0.32***	0.42***	0.39***	0.32***	0.42***
	(11.13)	(9.76)	(12.18)	(11.67)	(9.35)	(12.59)	(20.80)
Log fertilizer per ha	0.04***	0.04***	0.01**	0.04***	0.04***	0.02***	0.01
	(4.03)	(4.13)	(2.27)	(4.09)	(4.17)	(3.53)	(1.47)
Log tractor per ha	0.03***	0.03***	0.07***	0.03***	0.03***	0.08***	0.09***
	(3.15)	(2.85)	(6.93)	(3.53)	(2.67)	(7.86)	(8.85)
Log labor per ha	0.09***	0.07**	0.26***	0.11***	0.07**	0.39***	0.30***
	(3.43)	(2.53)	(7.67)	(4.23)	(2.50)	(12.26)	(9.51)
Land quality							
% Irrigated	1.27***	1.37***	0.34**	1.23***	1.49***	0.17	0.51***
	(8.59)	(8.84)	(2.19)	(7.68)	(9.15)	(1.38)	(5.07)
% Permanent pasture	-0.17	0.24	-0.56***	-0.35**	0.19	-0.71***	-0.49***
	(-0.98)	(1.07)	(-6.37)	(-2.24)	(0.82)	(-7.77)	(-7.39)
Total years of schooling				0.03***	0.04***	0.13***	0.08***
				(3.18)	(3.00)	(12.30)	(7.36)
Research effort							
Log. agric. R&D expend per ha							0.04***
							(4.77)
Constant	2.52***	3.29***	2.94***	3.27***	3.51***	4.66***	3.92***
	(5.86)	(7.48)	(9.51)	(7.85)	(7.84)	(15.30)	(15.04)
Observations	1,159	1,159	1,159	1,128	1,128	1,128	993
Number of countries	54	54	54	52	52	52	42
Country controls (Z)[b] included	Yes	No	Yes	Yes	No	Yes	Yes
ε_{it} autocorrelation	none	none	AR(1)	none	none	AR(1)	AR(1)
R^2	0.864	0.749	n.a.	0.886	0.788	n.a.	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level. This table was created using STATA Version 9 to achieve an exact replication of the results of Vollrath (2007).
[a] All specifications further include the total fertility rate, life expectancy, and year dummies.
[b] Z includes the Kaufmann, Kraay, and Zoido (2002) index of institutions, dummies for legal origin from La Porta et al. (1999), and the land quality index from Peterson (1987).

As can be seen, schooling has indeed not only in our sample but also in the one Vollrath had used a highly significant positive effect on agricultural productivity, regardless of the estimation technique (RE, FE or FGLS) and regardless of whether one further controls for the agricultural R&D expenditures per ha (see table 5 column 7 – corresponding to column 7 in table 6 in Vollrath's article). In fact, including such an education indicator raises the explanatory power of the model (see the increases in the R^2 between columns 1 and 4 and columns 2 and 5, respectively). These results are particularly interesting given that Vollrath states in footnote 5 of his article that he tried to include primary school enrolment rates as a proxy for the level of education which did not add any meaningful information to the regressions and were thus left out. Against the background of the methodological superiority of the Barro-Lee measure over the enrolment rates (see section 1.3) and the results in table 4, the contrasting results are not surprising. Instead, we interpret the findings of this second robustness check as support for the claim that the results are neither dependent on our particular dataset nor on the empirical methodology applied.

Table 6: Robustness checks 3

	(1) FE	(2) FGLS	(3) FE	(4) FGLS
	annual data		5-year averages	
(log) Livestock per ha	0.232***	0.243***	0.303***	0.295***
	(4.539)	(9.889)	(4.715)	(13.418)
(log) Fertilizer per ha	0.046**	0.021***	0.096***	0.084***
	(2.098)	(3.903)	(3.930)	(11.571)
(log) Tractors per ha	0.090***	0.064***	0.054**	0.047***
	(2.940)	(6.535)	(2.236)	(5.514)
(log) Workers per ha	0.262***	0.284***	0.197***	0.207***
	(3.229)	(7.710)	(2.711)	(8.307)
Area equipped for irrigation (%)	0.004*	0.002*	0.002	0.001
	(1.794)	(1.888)	(0.960)	(0.924)
Permanent meadows and pastures (%)	-0.009**	-0.005***	-0.005	-0.006***
	(-2.043)	(-3.665)	(-1.342)	(-4.246)
Life expectancy at birth	0.012***	0.011***	0.011**	0.011***
	(3.122)	(6.681)	(2.565)	(10.452)
Road sector energy consumption	-0.060	0.064	0.212*	0.196**
	(-0.203)	(0.657)	(1.987)	(2.472)
(log) Precipitation (mm)	0.040	0.021**	-0.026	0.008
	(1.361)	(2.010)	(-0.351)	(0.219)
Total years of schooling	0.046	0.027**	0.056**	0.044***
	(1.525)	(2.341)	(2.097)	(5.135)
Political risk index	-0.000	0.000		
	(-0.020)	(0.643)		
Constant	5.800***	5.532***	6.089***	5.746***
	(11.921)	(29.443)	(9.216)	(20.398)
Observations	1,120	1,120	396	395
Number of countries	69	69	74	73
Time fixed effects	yes	yes	yes	yes
Country fixed effects	yes	yes	yes	yes
ε_{it} autocorrelation	none	AR(1)	none	AR(1)
Wooldridge test statistic[a]	14.79		21.94	
Wooldridge test p-value	0.00		0.00	
R^2	0.902	n.a.	0.913	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level.
[a] Wooldridge test statistic is distributed as F(1, 68) in column (1), and F(1,70) in column (3).

As a third robustness check, we relax the assumption commonly made in the literature of a stable institutions index (table 6 - columns 1 and 2). Given that the ICRG political risk index is only available for the years 1984 onwards, this modification greatly reduces our sample to only 1,120 observations. It turns out that the political risk variable itself does not have any significant impact on agricultural productivity. In addition, the effect of the average years of schooling remains positive and statistically significant at the 5 percent level in our preferred model (FGLS) and only slightly misses significance in the FE specification.

Fourth, the model is re-estimated using five-year averages instead of annual data in order to minimize the effects of persistent temporary shocks (see table 6 - columns 3 and 4). Yet, this modification alters only slightly the magnitude of the coefficients for the education variable, but does not affect its statistical significance.

Fifth, it was argued earlier in this article that the average years of schooling as provided by Barro and Lee (2010) are methodologically superior to the measures previously used in the literature to approximate for the current stock of education in a country. However, the indicator still has the disadvantage of not solely measuring the education of the rural population which would be highly desirable given that the vast majority of agricultural labor comes from pastoral surroundings. Ulubaşoğlu and Cardak (2007) made an effort to address this issue and combined data from the UNESCO Educational Yearbooks and the World Bank Education Statistics in order to calculate the average years of schooling separately for urban and rural areas.[39] As a robustness check to our analysis, we take these data and use them to predict the average years of schooling for the rural population by first regressing the rural on the national years of education and its square (both from Ulubaşoğlu and Cardak (2007)). The resulting coefficients are then used to predict the average years of schooling for the rural population for all countries of our sample. As an alternative approach, we regress – as a first step – the ratio of rural to urban years of education on the nation's average years of education and make then – as a second step – use of the formula $s_{rural} = \frac{s_{national}}{\frac{\omega_{urban}}{r} + \omega_{rural}}$ to predict the avg. years of education for the rural population. The resulting predicted data are highly correlated with the Barro-Lee indicator for the average years of education used in the main part of our analysis ($\rho \approx 0.99$ and $\rho \approx 0.92$, respectively). Therefore, it is not entirely surprising that replacing the Barro-Lee measure with the predicted values for the rural population does not significantly change our results (the regression results obtained from

[39] However, due to data limitations this was only possible for a relatively small sample (in total 76 observations from 56 countries).

these two alternatives as well as the derivation of the above-described formula are provided in appendices A6-A9).

Sixth, we also examine whether the assumption of a common production function is driving our results. We do this by trimming the sample progressively by excluding the most and least capital intensive observations (as approximated by the tractor intensity and the fertilizer intensity - each defined as stated in footnote 35). It turns out that the results of our analysis are quite robust in the sense that the coefficient of the avg. years of schooling variable remains highly significant and positive even in substantially trimmed datasets (results not shown).

Lastly, Schultz (1999) and Wouterse (2011) claimed that increased farmer's human capital will not instantaneously translate into higher agricultural productivity and it is therefore necessary to consider lagged values of those variables. We took these objections seriously and included two-year-lags for the life expectancy and the average years of schooling instead of current values in our model (results not shown). However, it turned out that this does not materially affect the results of our analysis.[40]

1.7 Conclusion and policy implications

In this article, we re-examine the role of education for agricultural productivity in a cross-country framework. It is claimed that recent cross-country studies using sophisticated econometric methods failed to detect a statistically significant, positive impact of schooling as a consequence of inadequate proxies used to measure a country's stock of education. Using a large panel of 95 developing and emerging countries together with the newest version of the educational attainment dataset of Barro and Lee (2010), we find that education in fact has a significant positive impact on agricultural productivity worldwide which is robust to changes in specification and in estimation methods. The effect is sizeable, implying that an additional year of schooling for the whole population would raise agricultural productivity by approx. 3.2 % in the preferred

[40]As an additional test, some previous authors included the natural logarithm of the agricultural R&D expenditures per hectare in their models to account for the country's research effort. Despite a very poor availability of data, we did the same as a robustness check (results not shown) using data from the ISNAR Agricultural Research Indicator Series (Pardey and Roseboom 1989). While the magnitude of the coefficient for the average years of education remained relatively unchanged, the variable now missed statistical significance. However, we argue that this is rather due to the dramatically reduced sample of only 272 observations from 49 countries (compared to 1,685 observations from 74 countries before) than a consequence of the inclusion of the R&D expenditures variable which always remained statistically insignificant with t-values below 0.30. To support our claims of sample size problems, we can show that the schooling variable in this particular reduced subsample was not statistically significant even when applying our most basic regressions (without agricultural R&D expenditures) and the inclusion of the additional control variable did not materially change any of the coefficients. Hence, it is rather the smaller and apparently biased subsample that caused the education variable to be insignificant and not the effect of the additional control variable for R&D expenditures.

FGLS model. Furthermore, we find that only primary and secondary formation has a statistically significant positive impact on agricultural productivity. Finally, the effect of schooling was estimated separately for countries of different income levels. Our results suggest that the effect of education is generally smaller for the poorest countries. These findings are in line with the arguments proposed by Schultz (1975), Rosenzweig (1995), and Foster and Rosenzweig (1996) claiming that in very traditional agricultural settings where tasks are typically rather simple, one would expect the returns to education to be smaller (compared to countries facing rapid technical change).

The policy implications of our article are relatively straightforward. The positive impact of schooling on agricultural productivity found in our analysis supports the view that education is indeed one of the key ingredients to enhance productivity in developing and emerging countries. Hence, even governments of nations relying to a great extent on the primary sector should maximize efforts to increase the population's level of education. However, in particular for the poorest countries, our findings underline the complementarity of capital investments in the agricultural and the education sector since technical progress is needed to fully exploit the productivity-enhancing potential of schooling. Or to say it with the words of Foster and Rosenzweig (1996, p. 951):

> "…*the returns to investment in technical change will in general be higher when primary schooling is accessible and the returns to investment in schooling will be higher when technical change is more rapid.*"

We conclude with some caveats and further suggestions. First of all, our results are based on cross-country regressions which ought to be seen with the necessary caution since they all rely on relatively strong assumptions (e.g. the existence of a common meta-production function). However, we did our best to reduce the heterogeneity of the sample and are therefore relatively confident that this assumption is justifiable in our case. The fact that our macro findings are much more in line with the micro literature than previous macro findings further supports our contention. Secondly, we would have liked to account for differences in the quality of schooling in our analysis instead of solely focusing on its quantity. Eric A. Hanushek and Ludger Wößmann have worked extensively on this topic and compiled a dataset of test scores for approx. 50 countries worldwide (Hanushek and Wößmann 2007). However, this dataset has – at least from our perspective – the drawback that a large part of these countries are industrialized nations which we intentionally excluded from our sample (see section 1.4). In addition, it is – according to Hanushek and Wößmann (2007) – necessary to take an average of the test scores over at least the last 40 years, in order to obtain a reliable proxy for the educational performance of the entire labor force and not just a measure of the quality of current students. When doing so, one ends up with just one observation per country, thus having a time-invariant quality of schooling indicator which would in our preferred models be simply intercepted by the country fixed effect. In short, the unavailability of a time series schooling quality indicator unfortunately prevented us from accounting for differences in the quality of education in our analysis. Thirdly, as indicated earlier in this article, our results may actually underestimate the "full" impact of education on agricultural productivity since we are in our macro framework not able to adequately account for the endogeneity of activity choice by the farmers (e.g. Taylor and Yunez-Naude 2000; Yang and An 2002; Jolliffe 2004; Yang 2004). In particular, it may well be that individuals decide – as a consequence of education – to seek work (either partially or fully) in the non-agricultural instead of the agricultural sector where the returns to their knowledge are potentially higher. Given that our analysis is limited to agricultural productivity, we are obviously not able to (fully) capture the returns from schooling for those individuals.

Appendix to Chapter 1

Appendix A1: Data description and sources

a) Variables directly included in the regressions

Variable	Description	Source
(log) Net agricultural production per ha	Net Production (calculated as the total value of all agricultural production after deductions for feed and seed) in 1999-2001 international $ divided by total agricultural area in ha	FAOSTAT
(log) Livestock per ha	Own calculation of the number of cow equivalents by applying the weights from Hayami and Ruttan (1985) to the stocks of live animals obtained from FAOSTAT and then dividing the weighted sum by the total agricultural area in ha	FAOSTAT/ Own calculation
(log) Fertilizer per ha	Total fertilizer consumption in tons divided by total agricultural area in ha	FAOSTAT
(log) Tractors per ha	Number of agricultural tractors in use divided by total agricultural area in ha	FAOSTAT
(log) Workers per ha	Total economically active population in agriculture divided by total agricultural area in ha	FAOSTAT (revision 2006)
Area equipped for irrigation (%)	Share of the total agricultural area that is equipped for irrigation	FAOSTAT
Permanent meadows and pastures (%)	Share of the total agricultural area that is used as permanent meadows and pastures	FAOSTAT
Life expectancy at birth	Average life expectancy at birth in years	World Development Indicators (WDI)
Total fertility rate	Average number of births per woman	World Development Indicators (WDI)
Net enrolment ratio (%)	Net enrolment ratio for primary education (both sexes)	UNESCO Institute for Statistics (UIS)
Gross enrolment ratio (%)	Gross enrolment ratio for primary education (both sexes)	UNESCO Institute for Statistics (UIS)
Adult literacy rate (%)	Adult literacy rate (aged 15 and above - both sexes)	United Nations Development Programme (UNDP)
Total years of schooling	Number of years of total schooling achieved by the average person	Barro and Lee (2010)
Years of primary education	Number of years of primary schooling achieved by the average person	Barro and Lee (2010)
Years of secondary education	Number of years of secondary schooling achieved by the average person	Barro and Lee (2010)
Years of tertiary education	Number of years of tertiary schooling achieved by the average person	Barro and Lee (2010)
Road sector energy consumption	Per capita road sector energy consumption in kilotons of oil equivalents	World Development Indicators (WDI)
Road density	Own calculation of the road density defined as the total road length in km divided by the total land area in 100 sq. km	Own calculation
(log) Precipitation (mm)	Annual average precipitation on agricultural land in mm	Williams and Breneman (2009)
ICRG political risk	The ICRG political risk rating includes a total of 12 weighted variables covering political as well as social attributes (e.g. corruption, bureaucratic quality, external and internal conflict etc.)	International Country Risk Guide. PRS Group (2005).
English legal origin	Dummy variable. Code 1 if the country's legal origin is English common law	La Porta et al. (1999)
French legal origin	Dummy variable. Code 1 if the country's legal origin is French commercial code	La Porta et al. (1999)

German legal origin	Dummy variable. Code 1 if the country's legal origin is German commercial code	La Porta et al. (1999)
Scandinavian legal origin	Dummy variable. Code 1 if the country's legal origin is Scandinavian commercial code	La Porta et al. (1999)
Socialist legal origin	Dummy variable. Code 1 if the country's legal origin is Socialist/Communist law	La Porta et al. (1999)
Peterson land quality index	Land quality index for all agricultural land	Peterson (1987)

b) Variables used only for calculation reasons

Variable	**Description**	**Source**
Total agricultural area	Total agricultural area in ha	FAOSTAT
Road length	Total road length in km	Canning (1998)
Total land area	Total land area in sq. km	World Development Indicators (WDI)
GDP per capita, PPP	GDP per capita in PPP (constant 2005 international $)	Penn World Tables 7.0
Rural population (%)	Share of the population living in rural areas (% of total population)	World Development Indicators (WDI)

Appendix A2: List of observations dropped due to the two exclusion criteria

Country	**Observations dropped due to the ...**	
	natural disaster exclusion rule	**armed conflict exclusion rule**
Afghanistan	0	12
Albania	1	0
Algeria	0	2
Angola	0	8
Antigua and Barbuda	1	0
Australia	1	0
Bangladesh	1	0
Benin	1	0
Bolivia	1	0
Bosnia and Herzegovina	0	3
Botswana	1	0
Cambodia	1	10
Chad	0	1
Congo	0	1
Djibouti	3	0
Dominican Republic	0	1
El Salvador	1	5
Eritrea	2	2
Fiji	1	0
Gambia	1	0
Ghana	1	0
Guatemala	1	1
Guinea-Bissau	0	11
Guyana	1	0
India	1	0
Iran	1	8
Iraq	0	12
Israel	0	3
Jordan	0	1
Kenya	1	0
Kiribati	1	0
Lao People's Democratic Republic	1	0
Lebanon	0	9
Lesotho	1	0
Liberia	0	1
Libya	0	1
Malawi	1	0
Mauritania	3	0
Mozambique	2	4
Nicaragua	0	6
Niger	1	0
Rwanda	1	0
Sao Tome and Principe	1	0
Senegal	1	0
Sierra Leone	0	1
Somalia	0	3
Sudan	1	0
Swaziland	1	0
Tajikistan	1	2
Uganda	0	6
Vietnam	0	12
Zimbabwe	2	2

Appendix A3: Re-estimation of table 2 including a dummy variable for observations affected by major natural disasters or armed conflicts (instead of dropping those observations)

	(1) RE	(2) RE	(3) FE	(4) FE	(5) FGLS	(6) FGLS
(log) Livestock per ha	0.291***	0.297***	0.290***	0.299***	0.256***	0.285***
	(6.957)	(6.560)	(6.756)	(5.431)	(16.043)	(13.554)
(log) Fertilizer per ha	0.076***	0.056***	0.065***	0.059***	0.015***	0.016***
	(5.328)	(3.046)	(5.456)	(3.238)	(5.866)	(4.157)
(log) Tractors per ha	0.085***	0.098***	0.065***	0.078***	0.060***	0.064***
	(3.660)	(3.512)	(3.126)	(2.902)	(10.457)	(8.377)
(log) Workers per ha	0.164***	0.272***	0.112*	0.216***	0.188***	0.252***
	(2.874)	(4.351)	(1.835)	(2.797)	(8.421)	(8.641)
Area equipped for irrigation (%)	0.006**	0.004*	0.005*	0.003	0.006***	0.005***
	(2.320)	(1.764)	(1.815)	(1.395)	(6.304)	(4.568)
Permanent meadows and pastures (%)	-0.006**	-0.011***	-0.006*	-0.009**	-0.006***	-0.008***
	(-2.132)	(-4.228)	(-1.738)	(-2.402)	(-6.562)	(-7.224)
Life expectancy at birth	0.010**	0.013***	0.010***	0.012***	0.012***	0.011***
	(2.512)	(3.126)	(3.007)	(2.870)	(9.049)	(7.306)
Total years of schooling	0.059**	0.062***	0.053**	0.060**	0.033***	0.031***
	(2.427)	(2.773)	(2.019)	(2.325)	(4.492)	(3.556)
Road sector energy consumption		0.259**		0.227*		0.275***
		(2.259)		(1.787)		(3.816)
(log) Precipitation (mm)		0.037		0.032		0.024***
		(1.292)		(1.289)		(2.771)
Affected by nat. disaster/armed conflict	-0.002	0.027	-0.010	0.028	-0.017**	0.002
	(-0.079)	(1.094)	(-0.484)	(1.125)	(-2.223)	(0.217)
Constant	6.811***	5.578***	5.899***	5.907***	5.421***	5.554***
	(12.231)	(12.422)	(20.786)	(14.020)	(45.846)	(37.224)
Observations	2,871	1,663	3,395	1,743	3,395	1,743
Number of countries	79	69	95	74	95	74
Country controls included[a]	yes	yes	no	no	no	no
Time fixed effects	yes	yes	yes	yes	yes	yes
Country fixed effects	no	no	yes	yes	yes	yes
ε_{it} autocorrelation	none	none	none	none	AR(1)	AR(1)
R^2	0.891	0.937	0.843	0.914	n.a.	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level.

[a] All random-effects specifications include dummies for legal origin from La Porta et al. (1999) and the ICRG-institutions index.

Appendix A4: List of countries and number of observations

Country	Observations	Country	Observations
Afghanistan	28	Liberia	20
Albania	41	Libya	41
Algeria	40	Lithuania	11
Argentina	42	Malawi	41
Armenia	11	Mali	42
Bangladesh	41	Mauritania	30
Belize	33	Mauritius	24
Benin	38	Mongolia	34
Bolivia	41	Morocco	42
Botswana	41	Mozambique	36
Brazil	42	Myanmar	42
Bulgaria	42	Namibia	5
Burundi	37	Nepal	42
Cambodia	24	Nicaragua	36
Cameroon	42	Niger	38
Central African Republic	23	Pakistan	42
China	42	Panama	42
Colombia	42	Paraguay	42
Congo	31	Peru	42
Costa Rica	42	Philippines	42
Côte d'Ivoire	42	Republic of Moldova	11
Croatia	9	Romania	38
Cuba	42	Russian Federation	11
Cyprus	42	Rwanda	33
Democratic Republic of the Congo	26	Saudi Arabia	42
Dominican Republic	41	Senegal	41
Ecuador	42	Sierra Leone	41
El Salvador	36	South Africa	42
Fiji	41	Sri Lanka	42
Gabon	31	Sudan	41
Gambia	38	Swaziland	41
Ghana	41	Syrian Arab Republic	42
Guatemala	40	Tajikistan	8
Guyana	41	Thailand	42
Haiti	42	Togo	37
Honduras	42	Trinidad and Tobago	42
India	41	Tunisia	24
Indonesia	42	Uganda	35
Iran	33	Ukraine	11
Iraq	32	United Arab Emirates	31
Jamaica	42	United Republic of Tanzania	42
Jordan	41	Uruguay	21
Kazakhstan	11	Venezuela	23
Kenya	41	Vietnam	30
Kyrgyzstan	11	Yemen	37
Laos	37	Zambia	42
Latvia	11	Zimbabwe	36
Lesotho	41		

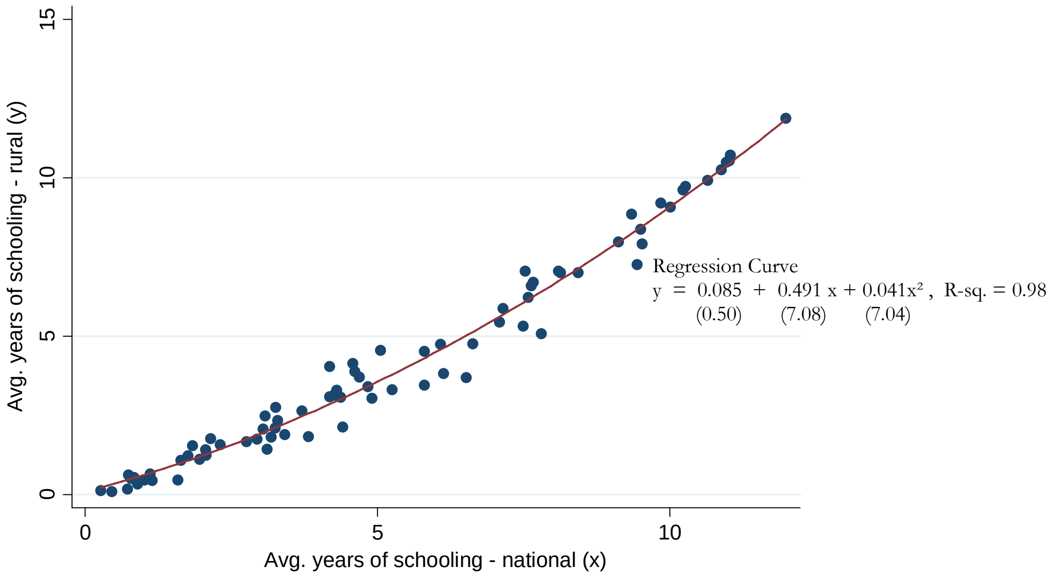
- **Total of 3,282 observations from 95 countries (basic FE-specification)**

Appendix A5: Regression results when the net enrolment ratio is used as a proxy for the level of education

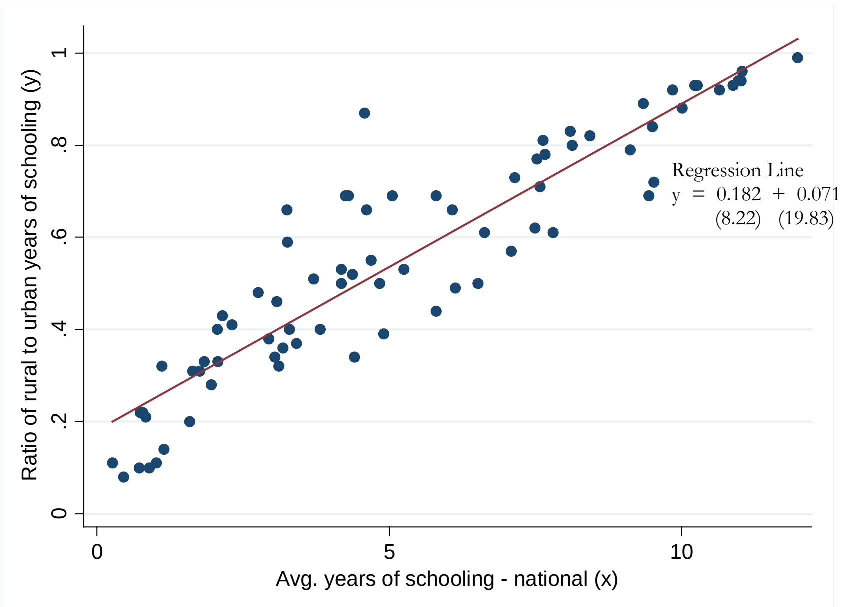
	(1) FE	(2) FGLS	(3) FE	(4) FGLS
(log) Livestock per ha	0.293***	0.291***	0.329***	0.307***
	(5.255)	(13.577)	(4.397)	(10.724)
(log) Fertilizer per ha	0.060***	0.017***	0.062**	0.029***
	(3.186)	(4.130)	(2.468)	(4.698)
(log) Tractors per ha	0.076***	0.063***	0.013	0.036***
	(2.814)	(8.285)	(0.421)	(2.982)
(log) Workers per ha	0.209***	0.236***	0.375***	0.322***
	(2.766)	(8.067)	(4.562)	(8.320)
Area equipped for irrigation (%)	0.004	0.005***	0.011***	0.008***
	(1.579)	(4.650)	(2.928)	(4.034)
Permanent meadows and pastures (%)	-0.010***	-0.008***	-0.007*	-0.005***
	(-2.670)	(-7.068)	(-1.914)	(-3.858)
Life expectancy at birth	0.012***	0.011***	0.019***	0.014***
	(3.173)	(7.239)	(3.700)	(6.939)
Road sector energy consumption	0.226*	0.264***	0.029	0.177*
	(1.838)	(3.615)	(0.195)	(1.887)
(log) Precipitation (mm)	0.027	0.021**	0.026	0.014
	(1.161)	(2.394)	(1.163)	(1.184)
Total years of schooling	0.063**	0.032***		
	(2.512)	(3.542)		
Net enrolment ratio			-0.003**	-0.000
			(-2.015)	(-0.566)
Constant	5.874***	5.561***	5.747***	4.614***
	(14.498)	(37.108)	(12.501)	(21.170)
Observations	1,685	1,685	813	807
Number of countries	74	74	83	77
Country controls included	no	no	no	no
Time fixed effects	yes	yes	yes	yes
Country fixed effects	yes	yes	yes	yes
ε_{it} autocorrelation	none	AR(1)	none	AR(1)
R^2	0.912	n.a.	0.847	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level.

Appendix A6: Relationship between the average years of schooling (national) and the average years of schooling (rural) (based on data from Ulubaşoğlu and Cardak (2007))



Appendix A7: Relationship between the average years of schooling (national) and the ratio of rural to urban education (based on data from Ulubaşoğlu and Cardak (2007))



Appendix A8: Derivation of the formula for s_{rural}

The avg. years of schooling for the whole nation ($s_{national}$) can be written as the weighted average of the years of schooling for urban (s_{urban}) and rural areas (s_{rural}) whereat the weights are the share of the population living in urban and rural surroundings (ω_{urban} and ω_{rural}, respectively).

$$s_{national} = \omega_{urban} s_{urban} + \omega_{rural} s_{rural} \tag{1.3}$$

In addition, the ratio of rural to urban education (r) is defined as

$$\mathrm{r} = \frac{\mathrm{s_{rural}}}{\mathrm{s_{urban}}} \tag{1.4}$$

which can be transformed to

$$\mathrm{s_{urban}} = \frac{\mathrm{s_{rural}}}{\mathrm{r}} \tag{1.5}$$

Replacing $\mathrm{s_{urban}}$ in equation (1.3) with (1.5) gives

$$s_{national} = \omega_{urban} \frac{s_{rural}}{r} + \omega_{rural} s_{rural} \tag{1.6}$$

This expression can be solved for $\mathrm{s_{rural}}$ yielding

$$s_{rural} = \frac{s_{national}}{\frac{\omega_{urban}}{r} + \omega_{rural}} \quad \text{q.e.d.} \tag{1.7}$$

Appendix A9: Results of the main regression when using the estimated average years of schooling for the rural population instead of the Barro-Lee measures

	Method 1		Method 2	
	(1) FE	(2) FGLS	(3) FE	(4) FGLS
(log) Livestock per ha	0.296***	0.289***	0.275***	0.287***
	(5.282)	(13.483)	(4.854)	(13.382)
(log) Fertilizer per ha	0.061***	0.017***	0.058***	0.014***
	(3.226)	(4.098)	(3.015)	(3.629)
(log) Tractors per ha	0.077***	0.063***	0.077***	0.065***
	(2.835)	(8.205)	(2.848)	(8.564)
(log) Workers per ha	0.217***	0.242***	0.255***	0.270***
	(2.802)	(8.141)	(3.325)	(8.632)
Area equipped for irrigation (%)	0.004*	0.005***	0.004*	0.005***
	(1.672)	(4.764)	(1.938)	(5.212)
Permanent meadows and pastures (%)	-0.010***	-0.008***	-0.010***	-0.008***
	(-2.820)	(-7.208)	(-2.945)	(-6.818)
Life expectancy at birth	0.013***	0.011***	0.012***	0.011***
	(3.377)	(7.239)	(3.008)	(7.138)
Total years of rural schooling	0.062**	0.025***	0.021**	0.013***
	(2.471)	(2.778)	(2.549)	(4.479)
Road sector energy consumption	0.217*	0.265***	0.221*	0.248***
	(1.830)	(3.626)	(1.815)	(3.400)
(log) Precipitation (mm)	0.027	0.021**	0.028	0.021**
	(1.172)	(2.390)	(1.204)	(2.383)
Constant	5.940***	5.625***	6.092***	5.671***
	(15.569)	(37.703)	(16.924)	(42.664)
Observations	1,685	1,685	1,685	1,685
Number of countries	74	74	74	74
Time fixed effects	yes	yes	yes	yes
Country fixed effects	yes	yes	yes	yes
ε_{it} autocorrelation	none	AR(1)	none	AR(1)
Wooldridge test statistic[a]	18.13		18.03	
Wooldridge test p-value	0.00		0.00	
R^2	0.913	n.a.	0.919	n.a.

Notes: The dependent variable is the logarithm of the net agricultural production per ha (in intl. $). Robust t-statistics are given in parentheses. Single asterisk (*) denotes significance at 10%, double asterisk (**) denotes significance at 5%, and triple asterisk (***) denotes significance at the 1% level.
[a] Wooldridge test statistic is distributed as F(1,73) in columns (1) and (3).

2. Chapter

Looking at Pro-Poor Growth from an Agricultural Perspective[41]

with Stephan Klasen

Abstract

Pro-poor growth has been identified as one of the most promising pathways to reduce poverty worldwide. Related research has developed a multitude of instruments to measure pro-poor growth using absolute and relative approaches and income and non-income data. This article contributes to the literature by expanding the toolbox with several new measures based on the concept of the growth incidence curve by Ravallion and Chen (2003) and the opportunity curve by Ali and Son (2007) that take into account the extraordinary importance of agriculture for poverty reduction in developing countries. The toolbox is then applied to three comparable household surveys from Rwanda (EICV datasets). Results indicate that Rwanda achieved over the first decade of the 2000s enormous progress in the income, but also in the education and health dimension of poverty, which was in various cases even pro-poor in the relative and strong-absolute sense. The new tools further reveal that agricultural productivity of the labor productivity-poor increased relatively (but not absolutely) faster than for the labor productivity-rich. Lastly, we find indications that the labor productivity-poor dispose of less education than the labor productivity-rich which may imply further potential to increase the poor's productivity levels if their education levels increased.

2.1 Introduction

Given that the eradication of poverty worldwide continues to be one of the most important challenges for humanity, much research effort has over the last decades been dedicated to the question how this ambitious goal may be achieved. As a result, the idea of growth that is particularly poverty-reducing, or "pro-poor" growth (PPG), emerged in the late 1990s/early 2000s as a way to accelerate poverty reduction (e.g. Klasen 2004, 2008; Grimm et al. 2007). Since

[41] The authors would like to thank Claude Bizimana and Andy McKay for facilitating them to use the EICV household data from Rwanda as well as Melanie Grosse and Ken Harttgen for granting them access to their do-files for the construction of the NIGICs. In addition, they are grateful to Miguel Almanzar, Ousmane Badiane, Thesia Garner, Simon Lange, Matin Qaim, John Ruser, Holger Seebens, Maximo Torero, and Konstantin Wacker as well as participants of the PEGNet Conference in Dakar (Senegal), the Convergence Project Workshops in Dakar and Goettingen (Germany), the research seminar of the Chair in the Economics of Social Policy at the University of Stellenbosch (South Africa), the AAEA Conference in Washington DC and the IARIW Conference 2014 in Rotterdam (Netherlands) for very helpful discussions and comments on earlier versions of this article. This research is part of a collaboration between the International Food Policy Research Institute (IFPRI) and the University of Goettingen and is supported by the German Federal Ministry for Economic Cooperation and Development.

then, this concept has received a great deal of attention and its focus on how the poor are benefitting from growth is seen as central to poverty reduction efforts (e.g. United Nations 2000; World Bank 2000a, b; Ravallion 2001; Klasen 2004; Besley and Cord 2007). The literature on pro-poor growth has developed various instruments providing researchers with the possibility to evaluate from an *ex-post* perspective the extent to which the poor benefited from recent developments in a country (these instruments are regularly referred to as the "pro-poor growth toolbox"). Most notably, Ravallion and Chen (2003) introduced the growth incidence curve (GIC) as a central tool to measure pro-poor growth which provides income growth rates by quantiles (e.g. vintiles or percentiles) ranked by income. Grosse et al. (2008) and Klasen (2008) showed with the so-called non-income growth incidence curve (NIGIC) that the concept of the GIC is also applicable to non-income dimensions of poverty such as education or health. Using the GIC/NIGIC one can then assess whether, according to the definitions proposed in Grosse et al. (2008) and Klasen (2008) and conditioning on income or the non-income dimension in question, growth was pro-poor in the weak absolute, relative or strong absolute sense (for details on the definitions: see section 2.2). A related approach was also pursued by Ali and Son (2007) who developed the so-called opportunity curves which are likewise focused on non-income dimensions of poverty and plot the level of access to certain social services against the cumulative share of the population ranked by income.

However, all of the above-mentioned tools focus too far on income and non-income dimensions of well-being. One reasonable way to further extend the concept is to examine how pro-poor productivity improvements have been. Given the extraordinary importance of agricultural productivity improvements for poverty reduction worldwide (e.g. World Bank 2007; de Janvry and Sadoulet 2010; Valdés and Foster 2010; Christiaensen et al. 2011), we suggest here to define the "poor" not only in terms of income, education or health, but also in terms of agricultural productivity. Such an approach can be readily implemented in the PPG-toolbox by slightly modifying some of the existing tools. The resulting new instruments can be called "productivity growth incidence curve" (PGIC) and "productivity opportunity curve" (POC) and allow us to look at pro-poor growth from a complementary, agricultural productivity-based perspective. When doing so, it is important to recognize that the land and the labor productivity-poor are not automatically the same households. Instead, these two subgroups can exhibit quite different characteristics and distinguishing between both groups in the analysis may hence provide us with interesting new insights in its own right.

To illustrate the potential of this extended toolbox, we then apply it to three waves of the nationally-representative EICV household survey from Rwanda (years 1999-2001, 2005-2006, and 2010-2011). Rwanda was chosen for our empirical application for four reasons. First, the Rwandan economy has since the genocide in 1994 gone through an impressive development and Rwanda belongs currently to the most rapidly growing countries in Sub-Saharan Africa (with an average annual growth rate of *per capita* income between 2000 and 2010 of 4.67% compared to an SSA average of 2.65% (WDI 2012)). Second, the Rwandan government has over the last decade undertaken considerable efforts to increase the population's access to social services (e.g. Saksena et al. 2011) which is one of the reasons why the United Nations consider Rwanda – despite the very challenging situation after the genocide – as one of the countries largely on track to achieve many of the Millennium Development Goals by the year 2015 (UNDP 2003, 2007). Third, Rwanda has the highest population density in Sub-Saharan Africa (approx. 431 inhabitants per square kilometer compared to an average of SSA countries of approx. 36 inhabitants per sq. km.) and its population keeps on growing rapidly at a rate of nearly 3% annually. Fourth, Rwanda remains a heavily rural and agriculturally based economy with more than 80% of the population living in rural areas and more than 75% of the workforce being employed in the agricultural sector (all numbers from WDI 2012). The combination of high population density, high population growth, and a largely agrarian economy requires the Rwandan government to find ways to increase the productivity of the agricultural sector to ensure food security as land is an increasingly scarce factor which cannot be expanded much anymore.

The results of our analysis indicate that Rwanda has in recent years achieved impressive progress in both, income and non-income dimensions of poverty. The observed progress was in many cases not only pro-poor according to the weak-absolute, but also according to the relative and, in various cases, even according to the strong-absolute definition (e.g. for adult literacy, access to improved sanitation and incidence of illness/injuries in the last 14 days). The new agricultural productivity-based tools, namely the monetary and crop-specific PGICs, reveal that the labor productivity-poor were able to increase their productivity levels relatively (but not absolutely) faster than the productivity-rich. Using the POCs (Type 1) it is further found that the labor productivity-poor exhibit in all three surveys lower education levels than the labor productivity-rich. Yet, as part of the recent expansion of education in Rwanda the absolute gap in education between these two groups has decreased slightly over the last years. Lastly, the POCs (Type 2) reveal considerably lower labor and land productivity levels for human capital-poor households in Rwanda.

The article proceeds as follows. Section 2.2 gives a brief overview on different concepts of pro-poor growth and the measurement tools so-far suggested in the PPG-literature. Section 2.3 discusses the policy relevance and limitations of the existing toolbox. In addition, it introduces the new instruments which enable us to look at pro-poor growth from an agricultural perspective. In section 2.4 it is explained why – at least in the Rwandan context – it is important to look at the land and labor productivity-poor separately. Section 2.5 describes the EICV household data which are used for the empirical application. The results of our pro-poor analysis are then discussed separately for the existing PPG-toolbox (section 2.6) and the new agricultural productivity-based tools (section 2.7). Lastly, section 2.8 summarizes the main results of our analysis and discusses potential limitations and policy implications.

2.2 Definition and measurement of pro-poor growth

Starting from the empirical finding that both lower initial inequality as well reductions in inequality are key drivers of poverty reduction (e.g. Ravallion 2001; Bourguignon 2004), the idea of pro-poor growth has emerged in the late 1990s/early 2000s as one of the key instruments to achieve sustainable poverty reduction (United Nations 2000; World Bank 2000a, b; Ravallion 2001; Klasen 2004). Despite numerous attempts, there is until today no consensus definition of what is meant by pro-poor growth (for attempts see e.g. McCulloch and Baulch 1999; Kakwani and Pernia 2000; Hanmer and Booth 2001; White and Anderson 2001; Ravallion and Datt 2002; Ravallion and Chen 2003; Duclos and Wodon 2004; Klasen 2004; Son 2004), with different groups of researchers/policy makers emphasizing different aspects (Duclos and Wodon 2004; OECD 2006).

As discussed above, we follow Grosse et al. (2008) and Klasen (2008), and distinguish between a weak-absolute, a relative, and a strong-absolute definition. According to the weak-absolute definition, every growth spell where the poor benefited to any extent (i.e. their aggregated growth rate was larger than zero) must be called pro-poor. The idea behind this notion is that to achieve poverty reduction (at least when applying an absolute concept of poverty) it is not important how the income growth of the poor compared to the one of the non-poor, but only that their incomes increased at all. However, one obvious downside of the weak-absolute definition is that it calls, somewhat counterintuitively, a growth spell pro-poor even when the poor benefited significantly less from it than the non-poor. The relative definition addresses this shortcoming and argues that growth episodes are only pro-poor if the poor's income grew relatively faster than the one of the non-poor (i.e. the growth rate of the poor was larger). Hence, growth rates must be biased in favor of the poor implying that relative inequality between the poor and the non-poor will fall.

The strong-absolute definition goes even a step further since it requires the *absolute* income gains of the poor to be larger than those of the non-poor. Some researchers describe such growth as "biased in a dramatic fashion in favor of the poor" (Klasen 2008, p. 421) or even "super pro-poor" (Kakwani et al. 2004, p. 4). As shown empirically by White and Anderson (2001) the criteria of the strong-absolute definition of pro-poor growth are only rarely satisfied in reality. However, this is particularly true if the analysis is focused on the monetary dimension. When analyzing progress in non-monetary dimensions of poverty, it is not completely unusual to observe pro-poor growth according to all three definitions since many of the indicators are bounded above, i.e. they have by definition a predefined maximum value (e.g. number of vaccinations, share of the population having access to certain services, years of schooling) which particularly facilitates the occurrence of pro-poor growth according to the relative and the strong-absolute definition. Also, as argued by Klasen (2008), in non-income dimensions the strong absolute definition is intuitively more plausible as absolute increments in health and education are usually seen as the relevant metric (rather than percentage changes which is more often used in the income sphere).

Based on the above concepts of pro-poor growth, various researchers have suggested tools and instruments aiming to measure *if* and also *how* pro-poor recent developments in a country were. Most notably, Ravallion and Chen (2003) introduced their growth incidence curve which graphically illustrates how the gains from economic growth were distributed. In order to construct the GIC, the individuals are first ranked for each period by their p.c. income and are then subdivided into p quantiles (e.g. vintiles or percentiles). For each of those quantiles the mean growth rate in p.c. income between $t-1$ and t is calculated separately being defined as

$$g_t(p) = \frac{y_t\,(p)}{y_{t-1}\,(p)} - 1 = \frac{L'_t\,(p)}{L'_{t-1}\,(p)}(\gamma_t + 1) - 1 \tag{2.1}$$

where $\gamma_t = \frac{\mu_t}{\mu_{t-1}} - 1$ is the growth rate in mean income μ and $L'_t\,(p)$ denotes the slope of the Lorenz curve at time t for quantile p. The GIC is then obtained by simply plotting the quantiles of the population ranked by their p.c. income on the horizontal axis against quantile-specific growth rates in p.c. income on the vertical axis. The concept of the GIC allows distinguishing between the above-mentioned three definitions of pro-poor growth. If $g_t(p) > 0$ (i.e. the quantile-specific growth rates in p.c. income are larger than zero; GIC above 0) for all poor quantiles, developments have been pro-poor according to the weak-absolute definition. If the (relative) GIC is sloped downwards (i.e. growth rates of p.c. income were larger for poor than for non-poor households), this indicates pro-poor growth in the relative sense. To test whether developments have even been pro-poor according to the strong-absolute definition, the mean change in p.c. income in *absolute* terms has to be calculated for each quantile. If the corresponding absolute GIC is sloped downwards, this implies pro-poor growth according to the strong-absolute definition.

To further assess the *degree* of pro-poorness of a growth spell, Ravallion and Chen (2003) introduced a measure called pro-poor growth rate (PPGR) which can be formally defined as (notion in line with Grosse et al. 2008)

$$PPGR = g_t^p = \frac{1}{H_{t-1}} \int_0^{H_t} g_t\,(\mathrm{p})\mathrm{d}p \qquad (2.2)$$

The $PPGR$ is equivalent to the area under the GIC up to the headcount ratio H_t and thus measures the average growth rate of the poor quantiles. Conveniently, it can be derived from the Watts poverty index and a pro-poor growth rate above 0 will reduce the poverty as measured by the Watts index. Moreover, if the PPGR exceeds the growth rate in mean income (GRIM), growth has been pro-poor according to the relative definition. To test for pro-poor growth in the strong-absolute sense, it is necessary to calculate analogously to (2.2) the mean *absolute* change of the poor

$$PPCH = c_t^p = \frac{1}{H_{t-1}} \sum_1^{H_t} c_t(p) \qquad (2.3)$$

This measure can be called "pro-poor change" (PPCH) and reflects the area lying under the absolute GIC up to the headcount (Grosse et al. 2008). If the PPCH exceeds the absolute change in mean income, then growth was pro-poor according to the strong-absolute definition.

One drawback of the growth incidence curves as introduced by Ravallion and Chen (2003) is that they are exclusively focused on the income dimension and therefore do not account for the multidimensionality of poverty (e.g. Sen 1983, 1998; World Bank 2000a) which is, for instance, reflected in the MDGs. Yet, Grosse et al. (2008) and Klasen (2008) showed that the general concept of the GIC and the related measures is equally applicable to non-income dimensions of poverty (using outcome based welfare indicators) yielding the so-called non-income growth incidence curves (NIGIC). These NIGICs are often presented in a "conditional" and an "unconditional" version. The former resembles very much the income GIC since on the horizontal axis the individuals are likewise ranked by their p.c. income. However, on the vertical axis, there is no longer the growth rate in monetary terms but in an appropriate non-income dimension (e.g. years of education, number of vaccinations etc.). Hence, conditional NIGICs answer the question to what extent different parts of the *income* distribution were able to increase their level in the contemplated *non-income* indicator. The unconditional NIGIC additionally differs from the GIC in the sense that on the horizontal axis, the individuals are now ranked by their attainment in terms of the respective non-income indicator. Thus, the question answered by the unconditional NIGIC is whether growth in, for instance, years of schooling was relatively or absolutely faster for the education-poor than for the education-rich. Even though there is obviously some correlation between the poor in monetary and non-monetary terms, this relationship is far from perfect (e.g. Anand and Ravallion 1993; Sen 1998). As a consequence, the above two versions of the NIGICs regularly yield different results whereat the information provided by both types can be of considerable relevance for policy-makers (see section 2.3).

A third approach to measure pro-poor growth[42] was introduced by Ali and Son (2007) with the so-called "opportunity curves" which are closely related to the idea of a social welfare function. The general idea of these curves is relatively similar to the one of a conditional NIGIC with the exception of two things. First, as in the case of conditional NIGICs, there are quantiles of the population ranked by p.c. income on the horizontal axis; however, these quantiles are in the case of the opportunity curves *cumulated*. With this procedure, Ali and Son (2007) want – in line with the inherent idea of pro-poor growth – to implicitly weigh the opportunities enjoyed by the poor higher than those enjoyed by the rich. As a second difference, the opportunity curve plots the *level* and not the *growth* in the access to certain services on the vertical axis against the cumulative share of the population.[43]

2.3 Policy relevance and limitations of the existing pro-poor growth toolbox

As the above explanations have shown, the literature so far has come up with a wide range of tools to measure pro-poor growth. The combination of all these tools provides researchers and policy makers with the possibility to *ex-post* evaluate who has benefited from recent developments in a country from quite different angles.

First, the "classical" growth incidence curve as introduced by Ravallion and Chen (2003) gives insights from the purely monetary perspective, thus indicating which parts of the income distribution experienced the highest growth rates/absolute increases in p.c. income whereas it cannot be distinguished whether such gains stem from direct participation in economic growth or

[42] We use the term pro-poor growth even though Ali and Son (2007) speak of "inclusive growth". Indeed, there are minor differences between the two concepts; however, for the purpose of this article, we consider these discrepancies as negligible. See Klasen (2010) for a further discussion of inclusive growth.

[43] It is noteworthy that if the quantiles on the horizontal axis were *not* cumulated in the case of the opportunity curve, the conditional NIGIC would simply be the first derivative of the opportunity curve.

from any kind of (governmental) transfers received. Nonetheless, the information provided by GICs is of considerable relevance for policy makers since it must be their goal to assure that no parts of the population are excluded from the benefits of economic growth. Such exclusion is not only problematic from a welfare point of view, but might also undermine opportunities for further economic growth (e.g. Galor and Zeira 1993; Persson and Tabellini 1994; Alesina and Rodrik 1994; Bourguignon 2004).

The insights provided by conditional NIGICs and opportunity curves can be seen as a complementary second perspective which is closely related to the first. In particular, such tools allow policy makers to evaluate whether the poor in monetary terms were able to improve their level of well-being in non-income dimensions. As pointed out by Grosse et al. (2008) and Klasen (2008), such an analysis can be seen as an outcome-based incidence analysis (e.g. Van de Walle and Nead 1995; Van de Walle 1998; Lanjouw and Ravallion 1999) which differs from the traditional expenditure incidence analysis in the sense that not the distribution of spending is measured, but the distribution of improvements in outcomes. In doing so, this variant circumvents the commonly criticized assumption of the expenditure incidence analysis that the consumer's benefit from the service can be approximated by the government's provision cost (Van de Walle 1998). From a policy point of view, the information provided by conditional NIGICs and opportunity curves may facilitate the maximization of the income poverty reducing effect of public expenditures for social services since it allows policy makers to evaluate whether the income-poorest have been reached by recent interventions. This can be seen as desirable in order to reduce the vulnerability of income-poor households and hence to enable them to break out of existing poverty traps.

The unconditional NIGIC approaches the issue of poverty from an additional third perspective because it no longer conceives of the poor in monetary but in non-monetary dimensions. Consequently, it provides policy-makers with information whether increased social services provision has really reached those being most deficient in the dimension of interest (e.g. health or education). Against the background of the not income-related MDGs 2-6, such information is crucial for many Sub-Saharan African governments since they must try to allocate their scarce resources as efficiently as possible to achieve progress towards the ambitious non-income targets.

All of these measures share the feature that they are concerned with the distributional pattern of *development outcomes*. But we may also be interested in the distributional pattern of key drivers of development outcomes. For example, it is commonly held that improvements in agricultural productivity are critical for poverty reduction in low income countries (e.g. World Bank 2007; de

Janvry and Sadoulet 2010; Valdés and Foster 2010; Christiaensen et al. 2011). The importance of agriculture is, of course, related to the fact that in most low-income countries a large share of the economically active population is still employed in agriculture (e.g. the average of Sub-Saharan African countries in 2010: 59.1% (FAO 2011)). Furthermore, land of good quality becomes increasingly scarce in numerous SSA countries due to limits to rising population density and poor soils. Against the backdrop of consistently high population growth rates (average of Sub-Saharan African countries in 2010: 2.50% (WDI 2012)), growth, poverty reduction and food security will heavily depend on success in raising agricultural productivity.

The extraordinary role of agriculture for poverty reduction has also been highlighted directly and indirectly by several authors from the pro-poor growth literature. Most fundamentally, the poor are regularly characterized as typically living in rural areas, depending directly or indirectly on agriculture for their subsistence and to mainly possess the production factor of (unskilled) labor and to some extent land while human capital is usually rather scarce (e.g. Alderman et al. 2000; Ames et al. 2000; Eastwood and Lipton 2000; Ravallion and Datt 2002; World Bank 2000a). Taking these features together, Klasen (2004) claimed that it is crucial for pro-poor growth to be concentrated on rural areas, to use intensively (unskilled) labor and to enhance agricultural incomes. Eastwood and Lipton (2000) even went a step further and directly related pro-poor growth to the issue of productivity when calling for greater attention that should be given to increasing agricultural productivity in order to attain a significant reduction of poverty. Against the background of such claims, it appears important to assess the distributional pattern of agricultural productivity growth to find out who has benefited from recent improvements (see also World Bank 2007).

We therefore propose and apply several new instruments which should be understood as complements to the existing PPG-toolbox and allow researchers and policy-makers to *ex-post* evaluate distributional developments in a country from a fourth, agricultural productivity-based perspective. The first tool, which we call the "productivity growth incidence curve" (PGIC) is closely related to the "classical" GIC of Ravallion and Chen (2003) and plots quantiles of the population ranked now by their agricultural productivity on the horizontal axis against quantile-specific growth rates (or absolute increases) of agricultural productivity on the vertical axis. The resulting curves give researchers and policy-makers the opportunity to evaluate to what extent the productivity-poor (e.g. in terms of agricultural land productivity) were able to increase their agricultural production per hectare, and thus allow an assessment of how improvements of agricultural productivity are distributed.

The second new tool relies on the idea of the opportunity curve of Ali and Son (2007) and we therefore call it "productivity opportunity curve" (POC) of which two different versions can be constructed. The POC (Type 1[44]) differs from the "classical" opportunity curve in the sense that we no longer have the cumulated share of the population sorted by income on the horizontal axis, but that quantiles are now sorted by agricultural productivity. Hence, such a POC (Type 1) investigates to what extent the productivity-poor are able to increase their education/health levels. In contrast to this, the second version of the productivity opportunity curve plots the cumulated share of the population sorted by education/health/human capital on the horizontal axis against the absolute levels of agricultural productivity on the vertical axis. Thus, it is the goal of the POC (Type 2) to answer the somewhat converse question, namely how the levels of agricultural productivity relate to deprivations in health or education.

Both of these questions are relevant for policy makers for several reasons. First, there is a broad literature indicating considerable productivity-increasing effects of improved farmer's education and health at the micro (e.g. Ali and Flinn 1989; Young and Deng 1999; Alene and Manyong 2006; Asadullah and Rahman 2009 for education and Antle et al. 1998; Croppenstedt and Muller 2000; Loureiro 2009; Ulimwengu 2009; Asenso-Okyere et al. 2011 for health) and the macro level (e.g. Reimers and Klasen 2013). Second, various studies analyzing the effects of different types of government expenditures on agricultural growth and poverty reduction in developing countries showed that investments in social services provision yield considerable returns in terms of agricultural productivity[45] (see e.g. Fan et al. 2000 and Fan et al. 2008 for India; Fan and Zhang 2008 for Uganda). Third, policy-makers are also interested in the question of whether those who suffer from particularly low agricultural productivity were benefiting from expanding opportunities in health and education. This is important from a multidimensional welfare perspective as one is interested in knowing whether those who are disadvantaged from an agricultural productivity perspective are benefiting from improvements in other dimensions of well-being. It is also important as improvements in health and education of the productivity-poor could, over time, set in motion improvements in agricultural productivity, thus facilitating an escape from income poverty.

[44] It should be noted that it would likewise be possible to construct a productivity-based form of a conditional NIGIC where one would then have vintiles of the population sorted by agricultural productivity on the horizontal axis and growth rates/absolute increases in terms of an appropriate non-income indicator (e.g. years of schooling) on the y-axis.

[45] To be more precise, these studies found particularly high returns for investments in education whereas the returns to government spending on health turned out to be rather limited.

2.4 The importance of distinguishing between the land and the labor productivity-poor

Before coming to a concrete application of the expanded PPG-toolbox, we would like to point to the importance of the regularly observed inverse relationship between farm-size and agricultural land productivity (often referred to as the IFSP relationship) for our newly introduced tools. As is well known, over the last decades there have been debates in the academic literature about the reasons for the IFSP given its apparent contradiction to the presumed scale advantage of larger farms due to the lumpiness of various expensive inputs such as farm machinery etc. (Binswanger et al. 1995; Kimhi 2006). According to Barrett (2010), it is possible to distinguish between three major explanations for this phenomenon. The first claims that for the inverse farm-size productivity relationship to exist, there must be failures on (multiple) factor markets which cause unobservable inter-household variation in the shadow prices of the production factors. This variation implies in turn differentials in the input intensity levels which are correlated with farm size and therefore could explain the IFSP (Barrett et al. 2010).[46] The second class of explanations states that an omitted variable bias (e.g. due to differentials in soil quality) is actually driving the IFSP[47] (e.g. Bhalla 1988; Bhalla and Roy 1988; Benjamin 1995). In contrast, the more recent third class of arguments (e.g. Lamb 2003) claims that measurement error/reporting bias in the farm/plot size data may be responsible for the IFSP relationship if smallholders misreport the size of their farms systematically differently from large landowners (Barrett et al. 2010).[48]

Turning to the Rwandan case, we observe in our data a clear inverse farm-size *land* productivity relationship, but a positive association between farm-size and *labor* productivity. This finding is in line with the relatively recent results of Ansoms et al. (2008) and Byiringiro and Reardon (1996) who empirically tested some of the above-described explanations of the IFSP for the Rwandan case. More specifically, Byiringiro and Reardon (1996) recognize that Rwandan households who dispose only of relatively small farms crop their land more intensively, make more ample use of the production factor of labor, let the land more rarely lie idle and invest much more in soil conservation activities. They further find that the marginal value product of land is considerably

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46 With regard to the question how such imperfections could actually look like, numerous suggestions have been made in the literature (e.g. Sen 1966; Bardhan 1973; Barrett 1996). A particularly well-known argument suggests that family and hired labor are actually only imperfect substitutes and that labor productivity of hired workers on large farms is positively associated with the level of supervision by the landowner (Feder 1985; Frisvold 1994). Hence, large landowners will regularly exhibit a higher optimal land-to-labor ratio than smallholders and – given imperfections on the land market – the IFSP relationship will emerge (Assunção and Braido 2007).

47 The underlying assumptions are that if better soil quality actually leads to higher output and if soil quality has a negative correlation with farm size, then the IFSP may be detected if the analysis does not adequately account for differentials in soil quality (Barrett et al. 2010).

48 It should be pointed out that various relatively recent articles have tried to empirically test the validity of the above-mentioned arguments, but have come to rather conflicting results (see e.g. Kimhi 2006; Assunção and Braido 2007; Barrett et al. 2010).

higher for the smallest farms than the common land rental rate while the marginal value product of labor amounts to as little as one third of the market wage. This kind of "bottling-up of labor on the smallest farms" (Byiringiro and Reardon 1996, p. 132) hence points in the direction that prevailing imperfections on the land and labor markets are the main drivers for the detection of the IFSP relationship in the Rwandan case.[49]

As a result, two things become evident that will be important for the following analysis. First, the fact that some households exhibit relatively high levels of land productivity does not necessarily imply that the production process on these farms is more efficient than on others since the higher land productivity could just have been "bought" at the expense of particularly high levels of labor input. Second, it therefore appears advisable not just to contemplate the land-productivity-poor and assume that these households are automatically also the labor productivity-poor. Instead, one should deliberately contemplate both groups separately, given that this may provide new insights in its own right about who the labor and land productivity-poor actually are and to what extent they benefited from recent developments in the country.

Lastly, it can be argued that for policy-makers both types of productivity-poor are actually different, but important target groups. First, the land productivity-poor could be in the focus of governmental efforts to increase agricultural productivity since – from an endowment perspective – the maximization of crop yields on *all* agricultural land has to have top priority in order to ensure food security in the future. Second, policy makers could also pursue the goal of increasing the agricultural productivity of the labor productivity-poor given that these households regularly exhibit relatively low consumption levels and small farm sizes (see section 2.7) and given that they are probably those most trapped by the above-described imperfections on the labor and land markets.

Given that the new instruments should be seen as complements to the classical devices from the PPG-literature, we will in the following empirical application first apply the existing toolbox (section 2.6). After this we will use in section 2.7 the newly introduced instruments (differentiating between land- and labor productivity-poor households wherever possible) to show that they can provide us with additional important insights about recent developments in Rwanda.

[49] Yet, it should be emphasized that Byiringiro and Reardon (1996) cannot entirely rule out the possibility that measurement error/reporting bias is also contributing to the detection of the IFSP relationship.

2.5 Data and methodology

For the empirical part of this article, we use data from three waves of the Rwandan Integrated Household Living Conditions Survey (EICV) which were collected in the years 1999-2001, 2005-2006, and 2010-2011. These three surveys are nationally representative and cover 6,420, 6,900, and 14,308 households, respectively (equivalent to 32,153, 34,785, and 68,398 individuals, respectively). The questionnaires of the surveys consist of a wide array of modules that include detailed questions e.g. about agricultural production, education, health, and household consumption. One particularity of the EICV consumption module is that each household was not just visited once, but numerous times (urban households eleven times at 3-day intervals and rural households eight times with 2-day intervals). Such an approach was chosen to ensure that payday-effects are adequately included for urban wage earners[50] and it can hence be expected that the consumption data from the EICV surveys will probably be more reliable than the ones obtained from other surveys where each household was just visited once. As a complement to the EICV2 household data, a community survey was conducted that includes a detailed price module for agricultural and non-agricultural goods on 28 local markets throughout Rwanda. The data from this price module will be used for the calculation of the agricultural production aggregate (see below).

As a first step of data preparation, we calculated a deflated[51] annual consumption aggregate for each household. In doing so, we mainly followed the approach used by the Rwandan National Institute for Statistics (NISR) in collaboration with the Oxford Policy Management Team (OPM) under the lead of Andy McKay and Emilie Perge (see NISR (2012) and appendix B1 for a description of the approach).

Secondly, we computed two measures of agricultural productivity (namely labor and land productivity) for each household involved in agriculture whereat both measures were calculated in a four step-procedure as follows. Given that Rwandan farmers frequently report their harvests in non-standard units (i.e. not in kilogram, liters etc.), we had – as a first step – to calculate the average weight for each crop-container combination to be able to convert the harvest reported in non-standard units to kilograms. As a second step, we used the above-described price data from the EICV2 community survey to calculate regional average prices per kg for each crop. The resulting prices are – as a third step – used to convert the total harvest in kg for each crop in each

[50] The issue of payday-effects can be expected to be rather less severe for rural areas of Rwanda where only small shares of the population are actually wage earners. Consequently, it was considered less important to maintain the 30-day reference period for rural households and a reference period of 14 days was applied instead (MINECOFIN 2002).

[51] When adjusting for price differences, we used January 2001 as a basis for our consumption aggregate.

of the in Rwanda typically two harvest periods into monetary values. The fourth step is then to simply aggregate the monetary values of those harvests on a household-level and to divide this sum either by the total size of *active* agricultural plots in hectares (i.e. excluding all plots lying idle in the time period under consideration) or by the total number of adults in a household who consider agriculture as their primary occupation[52]. The resulting measures of agricultural land/labor productivity reflect the theoretical[53] monetary value (in constant 2005 regional market prices) of the household's gross agricultural production per hectare of agricultural land/per adult worker in the 12 months preceding the survey.

As a last step of data preparation, we computed various health and education indicators for both surveys. Given that those measures are standard in the literature, we do not explain their calculation in further detail. Before starting to discuss the findings of our empirical application, we would like to emphasize that the results of the following PPG-analysis could generally have been presented in two alternative ways. First, we could have focused the analysis on the entire Rwandan population for the existing PPG toolbox and have then restricted the analysis to the agrarian population for our newly developed tools where we require detailed agricultural production data. However, this approach would prevent comparability of the results of the two sections since they were actually based on different samples. We therefore decided to restrict the sample throughout the entire PPG-analysis to the agrarian population which comprises in our case all households where at least one adult household member (aged 15 and above) reported working on the farm as his/her primary occupation. In this context, it should be noted that in Rwanda, as in many developing countries, the share of agricultural households declined in recent years. More specifically, while according to the EICV1 survey still approx. 89.20% of the population fulfilled our above definition of an agricultural household, this share reduced to 84.25% in the EICV2 and 76.82% in the EICV3 survey, respectively. To give the reader a first idea of our sample, table 7 provides an overview of the means of some key indicators for all three EICV surveys.

[52] Unfortunately, the information on agricultural labor contained in the EICV datasets are relatively crude and we therefore consider our measure for agricultural land productivity as more reliable.

[53] We are using the term *theoretical* since this number relies on the total amount harvested and not the total amount actually sold by the household, i.e. this number includes the monetary value of the harvest used e.g. for self-consumption, seeds, etc..

Table 7: Sample means for EICV1, EICV2 and EICV3 (agrarian population only)

	EICV1	s.e.	EICV2	s.e	EICV3	s.e
No. of households	5,376		5,399		10,843	
No. of individuals	26,705		27,668		52,978	
Household size	4.94	(0.034)	5.11	(0.032)	4.88	(0.023)
Age of household head	44.39	(0.223)	45.23	(0.219)	46.82	(0.173)
Share of male headed households (%)	67.44	(0.706)	71.86	(0.635)	72.30	(0.469)
Literacy rate (% - aged 15+)	51.73	(0.459)	63.15	(0.401)	67.45	(0.299)
Years of schooling (aged 15+)	2.38	(0.026)	3.42	(0.024)	3.84	(0.019)
Years of schooling of household head (aged 15+)	1.30	(0.036)	2.91	(0.041)	3.10	(0.031)
Share of households having access to impr. drinking water (%)	67.86	(0.707)	68.16	(0.654)	72.11	(0.447)
Share of households having access to impr. sanitation (%)	47.94	(0.751)	56.70	(0.699)	74.49	(0.448)
Illnesses/injuries in the last 14 days (%)	26.48	(0.298)	19.75	(0.248)	17.47	(0.182)
Annual consumption expenditures per a.e. (in 1000 RWF)	71.43	(0.734)	78.59	(0.749)	88.97	(0.621)
Farm size (hectare)	0.80	(0.014)	0.76	(0.015)	0.61	(0.008)
Number of persons having agriculture as their prim. occupation	2.17	(0.016)	1.98	(0.014)	1.76	(0.009)
Value of ann. gross production per ha (in 1000 RWF)	455.70	(8.022)	509.87	(6.505)	517.01	(3.829)
Value of ann. gross production per worker (in 1000 RWF)	100.26	(1.667)	128.51	(1.831)	140.31	(1.296)

One issue worth mentioning is the relatively low share of male headed households in Rwanda (compared to other Central African states) which has increased by almost five percentage points between EICV1 and EICV3. These low values are still a consequence of the Rwandan genocide in 1994 where mortality was much larger for men than for women. Besides that, considerable progress can be observed for all three education indicators and also for the three health indicators. Furthermore, it can be seen that Rwanda's rapid economic growth over the last years is also reflected in our micro data where the average annual consumption expenditures per adult equivalent (in constant January 2001 prices) grew from approx. 71,435 RWF in EICV1 to 88,973 RWF in EICV3[54]. Turning to the agricultural data, the increasingly important problem of land scarcity becomes obvious in the numbers for the avg. land size per farm household where levels were substantially below one hectare in all three surveys and, due to population growth, decreased even further between the EICV1 and EICV3 surveys from 0.80 to 0.61 hectare. These values are particularly alarming given that consequently a large share of Rwandan households cultivates less than 0.7 hectares which is – according to the Rwandan Ministry of Agriculture – the minimum land size required to provide a typical Rwandan family with sufficient food for their

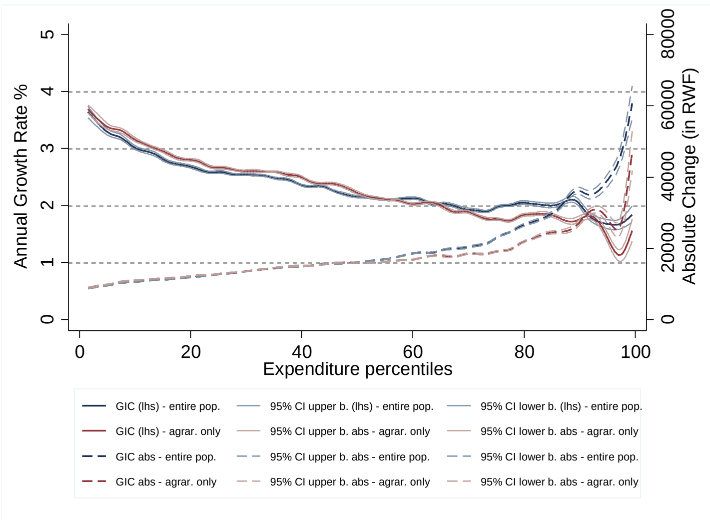
[54] It should be noted that these numbers differ from the ones reported in NISR (2012) due to two reasons. First, as described in appendix B1, we decided to exclude the use value of durable goods and the (imputed) rents for the household's dwelling from our consumption aggregate which leads to a lower consumption per adult equivalent. Second, other than NISR (2012) we used an exponent of 0.9 to explicitly account for economies of scale in the household which reduces our denominator when calculating the consumption expenditures per adult equivalent, thus leading to higher values for this indicator. It turns out that the first effect over-compensates the second and we therefore obtain lower values for the annual consumption expenditures per adult equivalent compared to NISR (2012).

living (Howe and McKay 2007). The calculated relatively high value of annual gross production per hectare of approx. 517,012 RWF (EICV3) in combination with the relatively low value of annual gross production per worker of approx. 140,310 RWF (EICV3) are therefore not entirely surprising given that farming is until today the main source of income for a considerable share of Rwandan households and that these households have – with limited access to agricultural land and scarce employment opportunities outside of agriculture – virtually no other alternative than trying to increase the productivity of their scarce land by the excessive use of (manual) labor.

2.6 Results for the existing PPG toolbox

Figure 1 approaches the question of who has benefitted from recent developments in Rwanda from the income[55] perspective. To illustrate how closely related the above-mentioned samples from the agrarian and the entire population actually are, we computed, for the case of the "standard" GICs (based on Ravallion and Chen 2003), the curves separately for the entire and the agrarian population.[56]

Figure 1: Income growth incidence curves: EICV1-EICV3



As can be seen, the resulting relative and absolute GICs[57] lie above zero for all percentiles of the respective populations (i.e. consumption expenditures of all percentiles increased between

[55] We speak here (and henceforth) of *income-poor* households even though it would be more precise to use the term *expenditure-poor* given that we based our rankings on the consumption expenditures per adult equivalent. However, we think that it is straightforward to still speak of the income-poor since the consumption expenditures were only used as a proxy for income due to the typically high volatility of household incomes in developing countries.

[56] It would have been possible to do this analogously for all other tools from the existing PPG-toolbox. However, we recognized that this would actually overload some of the graphs and would therefore make their interpretation quite complex.

[57] In line with Grosse et al. (2008) and Klasen (2008), we included in all figures shown below the bootstrapped 95% confidence intervals which are constructed by first drawing 200 random samples (with replacement) for each of the two periods and separately calculating the percentiles, growth rates and absolute increases for each of these drawings.

EICV1 and EICV3) which implies that growth has been pro-poor according to the weak-absolute definition. Comparing the annual growth rate in the mean which was 2.02 % for the agrarian population (see appendix B4) with the mean growth rate of the income-poorest 20%[58] of the same agrarian population (3.18%) further reveals that growth has also been pro-poor in the relative sense.[59] However, as indicated by the upward sloped absolute GICs (bold dashed lines), the absolute increases of the poor were for both samples smaller than those of the non-poor indicating that growth has not been pro-poor according to the strong-absolute definition (abs. increase in the mean of 17,538 RWF compared to an avg. increase for the poorest 20% of 10,793 RWF).

In order to account for the multidimensional nature of poverty, we use the literacy rate[60] for the population aged 15 and above as a first education indicator and construct opportunity curves following the approach of Ali and Son (2007)[61]. As can be seen in figure 2, the literacy levels for income-poor households are substantially below those of richer households. However, throughout the income distribution considerable progress between the three survey rounds can be observed which is reflected in an upward shift of the curves. This can e.g. be exemplified for the poor (again defined as the poorest 20%) of which in the EICV3 survey as much as 57.07% of all adults were literate (see appendix B3) while the corresponding share only amounted to 38.68% in the EICV1 survey which was collected approximately eleven years earlier.

This progress has to be judged as pro-poor in the weak-absolute (given that all poor vintiles of the population were able to increase their avg. literacy levels) and the relative sense (annual growth rate of the poor of 3.65% compared to a GRIM of 2.47%). In addition, progress was even pro-poor according to the ambitious strong-absolute definition with the increases for the poor being 18.39%-points (compared to an abs. increase in the mean of 15.18%-points).

In a second step, we then calculate the mean and the standard deviation over the 200 observations and use the resulting values to calculate the 95% confidence intervals.

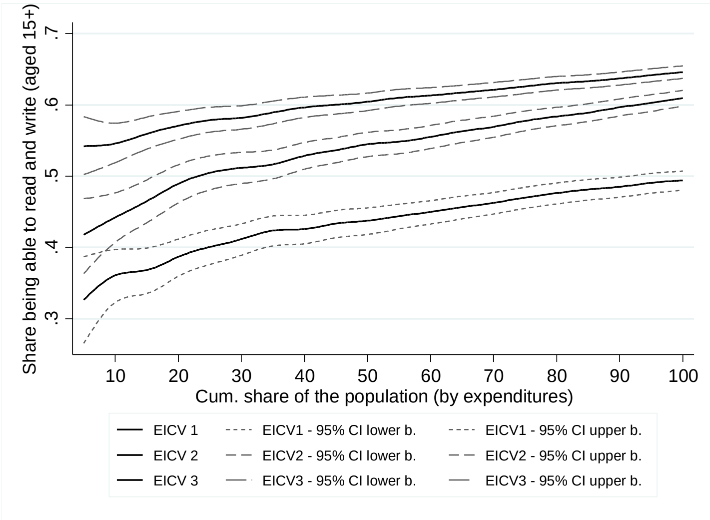
58 In the following analysis, we will always define the poor to be the poorest 20% of the population in terms of the dimension of interest. However, given that this threshold is obviously debatable, we included in appendix B4 also the growth rates/absolute increases of other shares of the population.

59 For the entire population, the finding would be very similar, yet with PPG in the relative sense being slightly less pronounced.

60 In line with the related literature, we define literacy here as the ability to read *and* write.

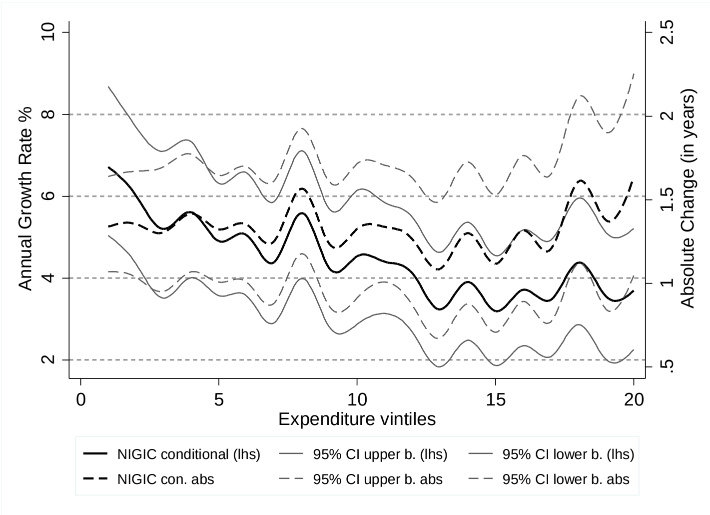
61 It should be noted that we calculated the 95% bootstrapped confidence intervals also for the opportunity curves in this article (Ali and Son (2007) did not show any confidence intervals in their original article). However, we think it is important to show the confidence intervals to give the reader a feeling for the precision of the estimates.

Figure 2: Opportunity curves for adult literacy (aged 15+)



Given that the adult literacy rate is for various reasons a rather imperfect education indicator (Barro and Lee 1993; for recent evidence see Reimers and Klasen 2013), we also use the average years of schooling for individuals aged 15 and above as a second measure for education.

Figure 3: Conditional NIGICs for avg. years of schooling (aged 15+): EICV1-EICV3



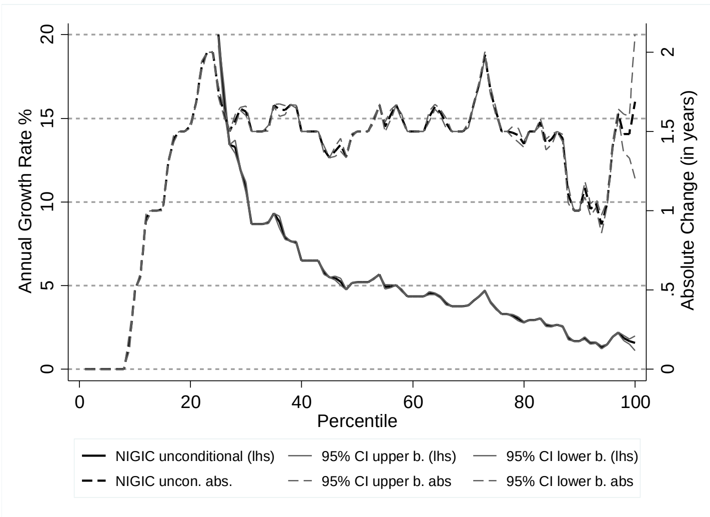
The conditional NIGICs for the avg. years of education (figure 3) generally confirm the above-described results for the adult literacy rate. In particular, we find that all vintiles[62] of the population were able to increase their average level of schooling in the time period under consideration (i.e. growth has been pro-poor in the weak-absolute sense) and that the annual growth rate of the poor (5.89%) exceeded the growth rate in the mean (4.35%) which implies that growth has been pro-poor according to the relative definition. Yet, for this indicator,

[62] In line with the recent literature (e.g. Grosse et al. 2008 and Klasen 2008), we used vintiles instead of percentiles of the population for the conditional NIGICs (and likewise for the opportunity curves) given the relatively high heterogeneity of non-income achievements (and related growth rates) within income quantiles.

progress was not clearly pro-poor in the strong-absolute sense since the absolute increase for the poor (1.35 years of schooling) was almost identical to the absolute increase in the mean (1.34 years of schooling). Nevertheless, it should be pointed out that for both indicators the magnitude of the achieved progress is impressive given that the adult literacy of the income-poor increased in only about eleven years by as much as 18.39%-points or put differently, an income-poor Rwandan adult observed in the EICV3 survey had received approx. 1.35 years of schooling more than an income-poor adult observed in the EICV1 survey. This is particularly remarkable since most of the older individuals no longer attend any form of education and act therefore as a kind of inbuilt-inertia for the indicator; thus the improvements derive mostly from poorly educated cohorts dying and being replaced by better educated younger cohorts.

As a last step of the analysis in the field of education, we calculated the unconditional NIGIC for the avg. years of schooling where we no longer rank households by income per adult equivalent on the horizontal axis but by the endowment in terms of education (i.e. years of schooling). As can be seen from figure 4, the shape of the unconditional NIGIC greatly differs from the conditional NIGIC which is to some extent a consequence of the fact that there is a considerable share of households where no adult has received any education.

Figure 4: Unconditional NIGICs for avg. years of schooling (aged 15+): EICV1-EICV3



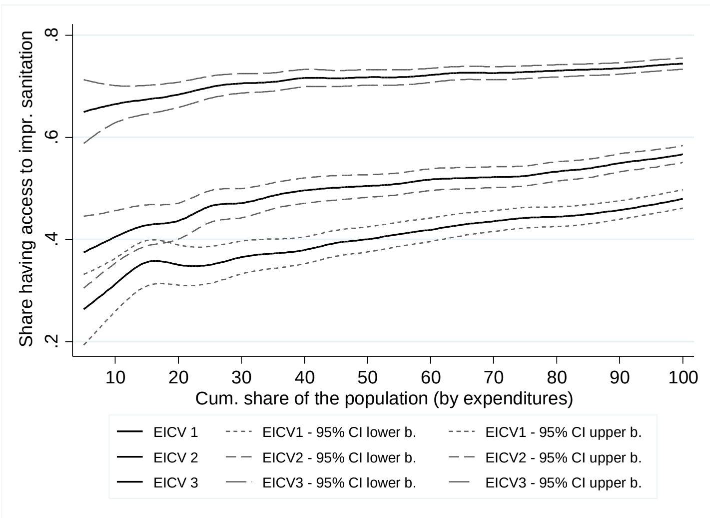
However, this share decreased extraordinarily between EICV1 and EICV3 from approx. 24% to 8% which is reflected in the graph by the increase of the *absolute* NIGIC[63] from 0 to almost 2 years between the percentiles 9 and 24. From a pro-poor growth perspective, this means that considerable progress has been made in providing the education-poor with schooling.

[63] It should be noted that a relative unconditional NIGIC is up to percentile 24 not defined given that the denominator for the growth rate is in these cases equal to zero. For this reason, we also refrain from categorizing the progress into the three pro-poor growth classifications.

Furthermore, also for those quantiles where household members had already in the EICV1 survey received some education (to the right from percentile 24), the absolute increases in terms of schooling were – with an average increase of almost 1.5 years – very impressive. When comparing these findings to the results presented by Grosse et al. (2008) for Bolivia (1989-1998) and Burkina Faso (1994-2003), it can be recognized that Rwanda in fact was much more successful than Burkina Faso and even slightly more successful than Bolivia in increasing the education-levels of the education-poor.

Turning to the health dimension of poverty, we analyzed – as a first step – how the agrarian population's access to improved sanitation[64] developed in the time period under consideration. As shown by the opportunity curves in figure 5, the level of access to improved sanitation of poor households was considerably below the one of non-poor households at the time of EICV1. However, we see a considerable upward shift of the opportunity curves between EICV1 and EICV3 which is particularly large between EICV2 and EICV3. For example, the access to improved sanitation for the poorest 20% of the population increased from 35.1% (EICV1) to 68.4% (EICV3). Not surprisingly, this progress has to be judged as pro-poor according to all three definitions given that the access to improved sanitation has increased for all vintiles of the population and that both, the annual avg. growth rate (6.43% compared to a GRIM of 4.09%) as well as the avg. absolute increase (33.33%-points compared to an avg. absolute increase in the mean of 26.54%-points) have been higher for the poor than for the non-poor.

Figure 5: Opportunity curves for access to improved sanitation

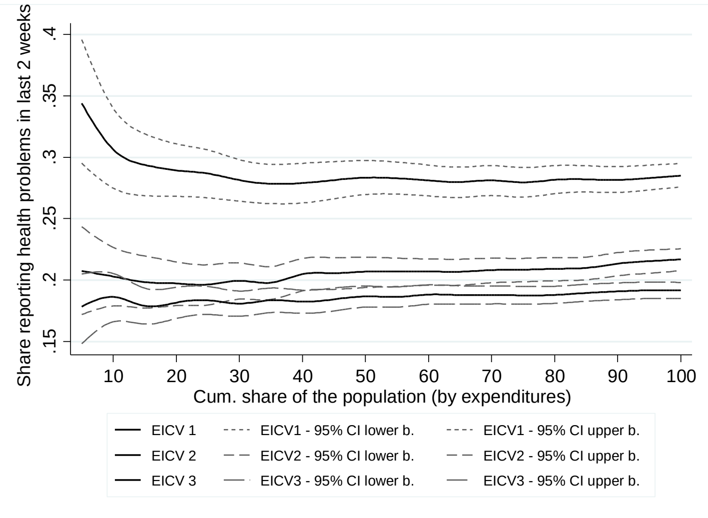


[64] The categorization of sanitation facilities into improved and unimproved systems was done based on the definition provided by the Joint Monitoring Programme of UNICEF and WHO (JMP 2012).

As a second health indicator, we then looked at the access to improved drinking water sources[65] (appendix B5) where the picture is much less positive and the data suggest that the access of the income-poor to improved drinking water sources only improved marginally between the surveys (68.8% in EICV1 to 69.3% in EICV3). Despite the admittedly relatively broad confidence intervals of these curves, this is certainly a point which requires particular attention of the Rwandan authorities and where considerable progress can potentially be made in the future.

Lastly, we analyzed data for self-reported illnesses/injuries in the two weeks preceding the interview (figure 6). Against the background that the perception of being ill or injured may differ greatly between individuals, such numbers have always to be treated with caution. However, one would expect that – on average over the population – this subjective assessment will remain relatively stable over time (at least for relatively short time periods) and it may therefore be worthwhile to look at time trends for this indicator.

Figure 6: Opportunity curves for health problems in the last two weeks



The resulting opportunity curves in figure 6 reveal an extraordinarily rapid reduction of levels for this indicator especially between EICV1 and EICV2. While in the EICV1 survey still 28.94% of the poor were reportedly injured or ill in the two weeks preceding the interview, this share amounted just to 19.73% in EICV2 and decreased further to 18.15% in EICV3. This enormous progress implies pro-poor growth according to all three definitions since the incidence of illness declined for all poor quantiles of the population and decreased more rapidly in relative and absolute terms for the poor than for the non-poor (-4.11% for the poor compared to a GRIM of -3.55% and -10.79%-points reduction for the poor compared to an abs. decrease in the mean of -9.36%-points).

[65] The categorization of drinking water facilities into improved and unimproved systems was likewise done on the basis of the definition from JMP (2012).

2.7 Results for the agricultural perspective

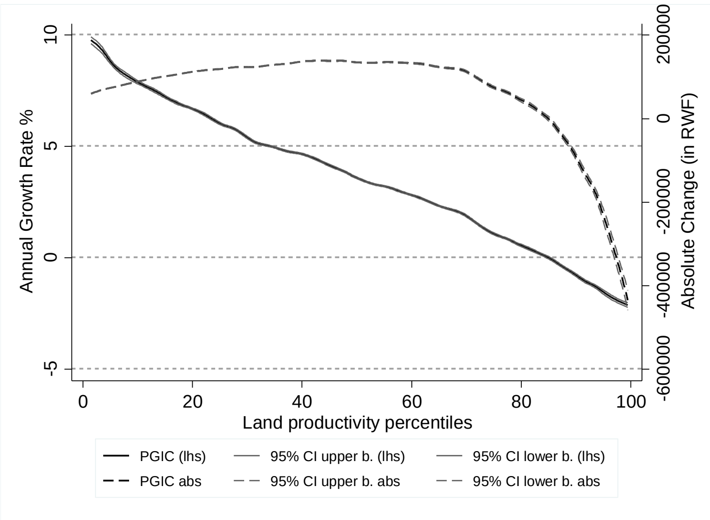
Until now, we applied the existing pro-poor growth toolbox and concluded that household per adult equivalent incomes have not only increased in the mean, but also for the poor significantly between the three surveys. Furthermore, the analysis revealed that the education and health levels of the income-poor (and the education-poor for the case of the years of schooling) improved considerably and that this progress has on various occasions been pro-poor not only according to the weak-absolute and relative, but also according to the strong-absolute definition of pro-poor growth.

We now want to look at pro-poor growth from the agricultural perspective and ask to what extent the poor in terms of agricultural productivity were able to increase their productivity levels between the three survey rounds. As emphasized in section 2.4, it would be misleading to simply assume that the land and the labor productivity-poor are in the Rwandan case the same households. This can be illustrated with the tables in appendices B6 and B7 which nicely show that both groups actually exhibit quite different characteristics with the labor productivity-poor being considerably poorer (particularly in terms of land holdings, but also in terms of consumption per adult equivalent). As a consequence, we will in the following analysis distinguish between the land and the labor productivity-poor whenever our data allows.

As a first step of our analysis for the agricultural perspective, we therefore calculate a *monetary* productivity growth incidence curve where we use as our indicator for agricultural productivity the monetary measure for the household's gross agricultural production per hectare of agricultural land in the 12 months preceding the survey (see section 2.5).

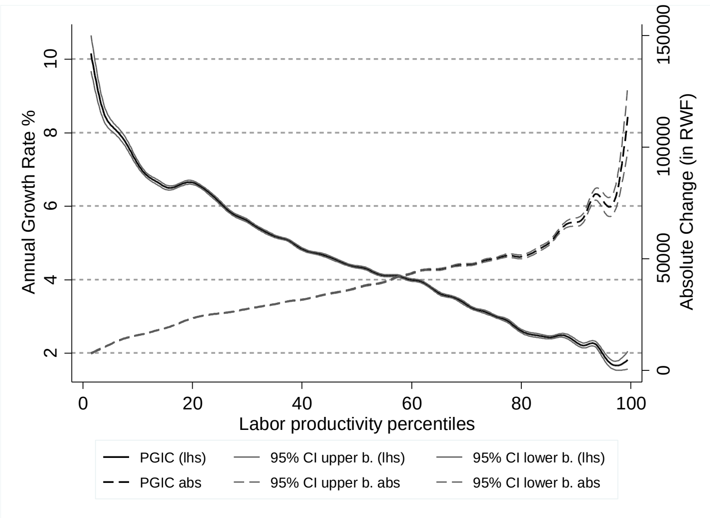
As shown in figure 7, the resulting relative monetary PGIC has quite narrow confidence bands and is clearly sloped downwards indicating that agricultural productivity increased relatively faster for land productivity-poor households whereas productivity growth was even slightly negative for the land productivity-richest households. In absolute terms, the curve exhibits a somewhat different pattern with a maximum absolute increase in agricultural productivity for percentile 47. Still, the achieved progress has to be judged as pro-poor according to the weak-absolute, the relative and the strong-absolute definition (abs. increase in the mean of 61,313 RWF compared to an avg. increase for the poorest 20% of 87,971 RWF).

Figure 7: Monetary land productivity growth incidence curves: EICV1-EICV3



In line with our above explanations, we calculated – as a second step – the corresponding monetary PGICs for agricultural *labor* productivity (figure 8). Again, the absolute PGIC lies above zero for all productivity-poor percentiles and the relative PGIC exhibits a clearly downward sloped pattern which indicates pro-poor growth in the weak-absolute and the relative sense. Yet, given the upward sloped absolute PGIC, one has to acknowledge that labor productivity growth has not been pro-poor according to the strong-absolute definition. From a poverty perspective these results are nevertheless quite encouraging given that they imply that the labor productivity-poor were able to increase the output per worker considerably and even relatively faster than the labor productivity-rich.

Figure 8: Monetary labor productivity growth incidence curves: EICV1-EICV3



The monetary PGICs in figures 7 and 8 are generally a relatively straightforward way to evaluate to what extent the productivity-poor (either land or labor productivity) were able to increase their productivity levels. However, there are at least two reasons why the results of these monetary PGICs should be interpreted with some caution. First, in contrast to many of the non-income indicators, increases in agricultural productivity may not be the result of a (more or less) steady process but are of relatively volatile nature e.g. they could be due to adverse/good weather conditions. Therefore, one should be rather careful when interpreting the *levels* shown in figure 7 and 8 since it could theoretically be that the EICV1 data were simply collected in a very bad and/or the EICV3 data in a very good year in terms of agricultural harvest. Second, there may be differentials in the crops planted by the productivity-poor and -rich. For instance, it could be that we observe declining relative PGICs due to the fact that harvests of the most prevalent crops planted by the productivity-rich were rather bad while harvests for the most prevalent crops of the productivity-poor were rather good.[66] Despite these downsides, we interpret the results in figures 7 and 8 as first indications that the increases in agricultural land/labor productivity were rather distributed in a pro-poor manner.[67]

Against the background of the above-described drawbacks, we calculated as a third step of our productivity analysis *crop-specific* PGICs for land productivity[68] for the three most important single crops in Rwanda (according to the land use numbers reported in the EICV3 survey) which are in decreasing order of importance: beans, manioc and maize (see appendix B8 for the exact share of each crop in the three surveys). Taken together these three crops account for almost half of all agricultural land reported which underlines the crucial importance of the crops for Rwanda's agricultural sector.

In comparison to the monetary PGICs, these crop-specific PGICs have the advantage that the underlying productivity measure is no longer a combination of the (theoretical) revenues generated by various crops per one hectare of agricultural land, but that it is now simply the total amount harvested (in kilograms) of the crop of interest per hectare. This basically solves the

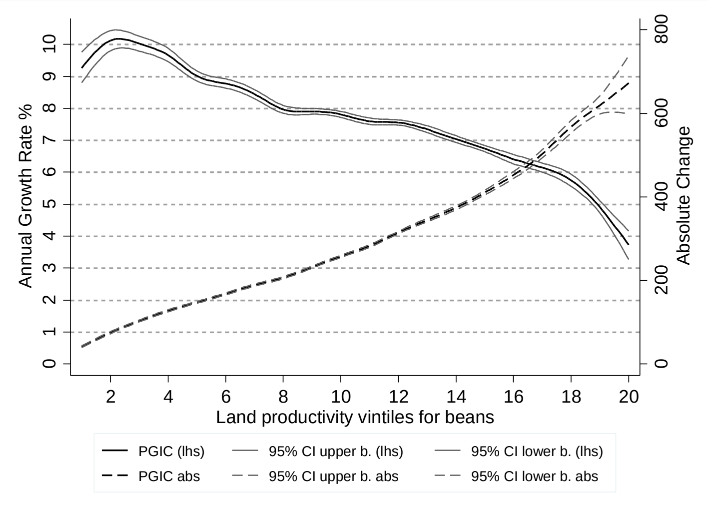
[66] One could argue that our results may be driven by systematic measurement error in the harvests of the poor in one of the two contemplated surveys. However, we are quite confident that this is not the case given that we observe quite similar patterns also for sub-periods (EICV1-EICV2 and EICV2-EICV3, respectively) as well as independently for various crops.

[67] In an attempt to account for potentially differing levels of capital intensity, we re-calculated figures 9 and 10 for net instead of gross agricultural land/labor productivity (results not shown). We noted that the overall input levels are very low in all three surveys. In addition, the overall pattern of the curves remains virtually unchanged with only minor shifts in the location of the curves, but not in the shapes. Unfortunately, input data are in our dataset of highly aggregated nature (no plot-level input data available) and we therefore decided to always show graphs for gross productivity for comparability reasons.

[68] Given that the EICV data do not contain detailed information on labor input by crop, we were unfortunately not able to calculate crop-specific PGICs for agricultural labor productivity.

second of the two above-described problems since it is no longer possible that a certain shape of the PGIC is simply a consequence of different crops planted by the productivity-poor and -rich.[69]

Figure 9: Land productivity growth incidence curves for bean production: EICV1-EICV3



As can be seen from the crop-specific PGICs for bean production in figure 9, all vintiles of the bean-producing population were able to increase their agricultural land productivity considerably in the time-period under consideration (even though one should – as noted above – interpret the levels with some caution). What is even more interesting is, however, the shape of the relative PGIC which has a negative slope indicating that the productivity-poor (in terms of bean production per hectare) were able to increase their land productivity relatively faster than the average (annual avg. growth rate for the poor of 9.77% compared to a GRIM of 6.24%), i.e. growth has been pro-poor in the relative sense. A similar picture (even though with slightly different shapes of the crop-specific PGICs) is obtained when looking at manioc and maize production likewise indicating pro-poor growth according to the weak-absolute and the relative definition (see appendices B9 and B10).[70] In this sense, the results of the crop-specific PGICs are in line with the findings from the monetary PGICs and are quite encouraging that recent efforts of the Rwandan government to increase agricultural land productivity of the productivity-poor were successful. Nevertheless, it should be noted that the absolute harvest increases of the productivity-non-poor were – for all three crops considered – substantially larger than those of

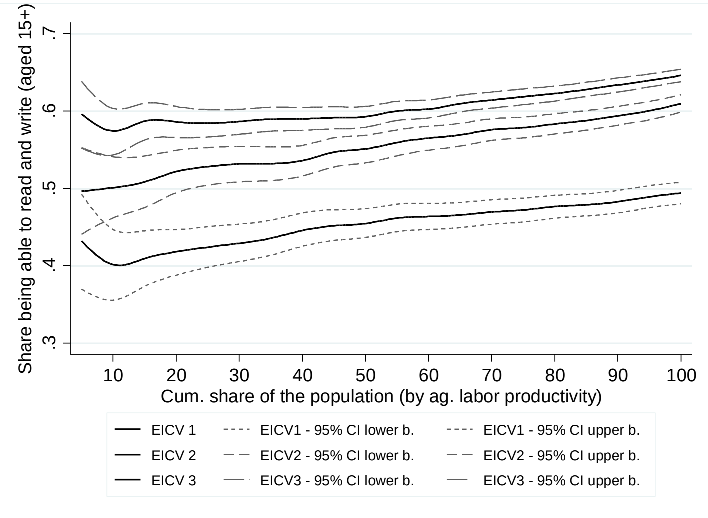
[69] It should be noted that the above-described analysis still assumes both homogeneity in the crops and in the quality of the harvest. However, given that these are common assumptions in the analysis of household-level production data and that there is no real way to solve these issues, we accept it as one possible source of measurement error in our analysis.

[70] To illustrate that this favorable result is by no means guaranteed, we show in appendix B11 the land PGIC for maize production between EICV1 and EICV2 which exhibits clearly negative sloped curves (i.e. an anti-poor development in the relative and the strong-absolute sense).

the productivity-poor which implies that the absolute gap between the two groups has risen considerably.

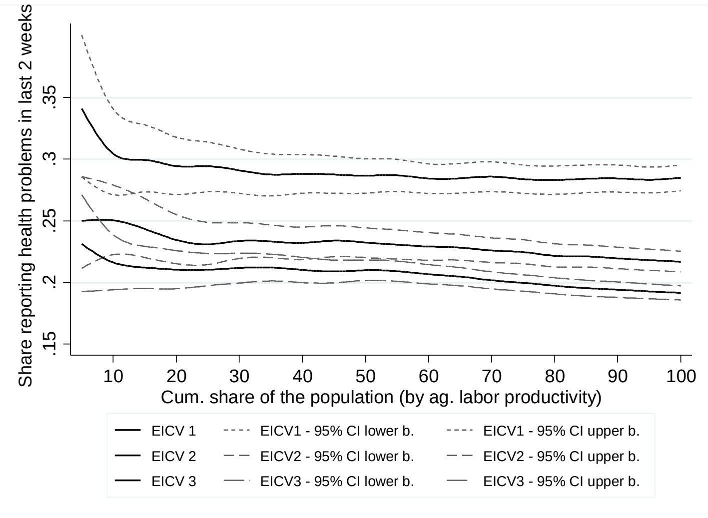
Until now, we studied recent developments in Rwanda from a purely productivity-based perspective trying to answer the question to what extent the land/labor productivity-poor were able to increase their yields per hectare/worker. Given the above-described evidence from the micro and macro level of productivity-enhancing effects from increased education and health, we ask as a next step how well the labor productivity-poor are equipped in these two dimensions. This is done by constructing labor productivity opportunity curves (Type 1) for the adult literacy rate (figure 10) as well as the incidence of illness/injuries in the two weeks preceding the survey (figure 11 - the corresponding curves for agricultural land productivity are provided in appendices B12 and B13).

Figure 10: Labor productivity opportunity curves (Type 1) for adult literacy (aged 15+)



As shown in figure 10, all three labor productivity opportunity curves are sloped upwards implying that literacy levels of the productivity-poor were in all surveys below those of the productivity-rich. Yet, the POCs further show that the productivity-poor were not excluded from the expansion of education in Rwanda and were in fact able to increase their average literacy levels in the time period under consideration from approx. 41.83% (EICV1) to 58.62% (EICV3). This has to be judged as a quite impressive development which was not only pro-poor in the weak-absolute, but also in the relative and strong-absolute sense (abs. increase in the mean of 15.18%-points compared to an avg. increase for the poorest 20% of 16.79%-points). Hence, the absolute education gap between the labor productivity-poor and -rich has decreased slightly during the time period under consideration. Turning to self-reported health problems in the last two weeks, figure 11 reveals slightly higher incidence levels and a smaller decrease in the indicator of interest for the labor productivity-poor compared to the labor productivity-rich (yet with relatively wide confidence intervals) which implies that developments have been pro-poor in the weak-absolute, but not in the relative and strong-absolute sense. When comparing these findings to those for the land productivity-poor (appendices B12 and B13), we find indications that the education-levels of the land productivity-poor are likewise smaller than those of the land productivity-rich (particularly in the EICV2 and EICV3 survey), but we do not find any evidence for differentials in the incidence of health problems between the land productivity-poor and -rich.

Figure 11: Labor productivity opportunity curves (Type 1) for health problems in the last two weeks

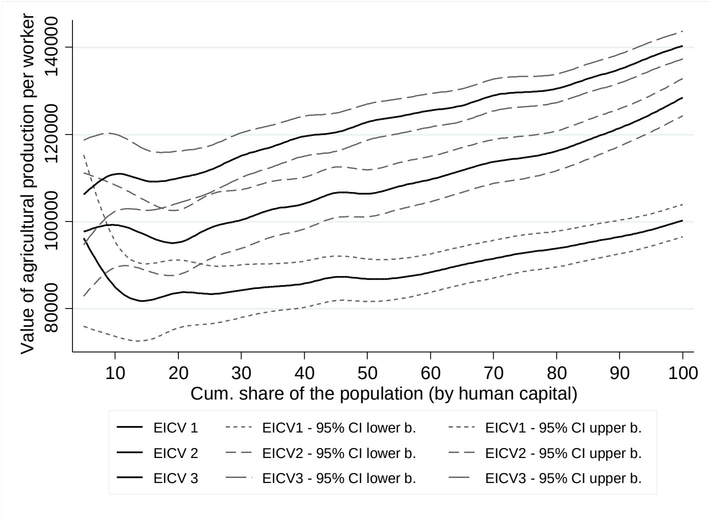


As a last step of our analysis, we pursue the converse question, namely whether the productivity levels of the human capital-poor are lower or higher than those of the human capital-rich. To be able to answer this question, we calculate productivity opportunity curves (Type 2) separately for land and labor productivity which are constructed in a two-step-procedure as follows. First, we use principal component analysis to calculate a human capital index which reflects each household's endowment with human capital.[71] Based on this index we then rank households on the horizontal axis (cumulated) and plot this against the land/labor productivity levels on the vertical axis. The resulting POCs (Type 2) for the case of agricultural labor productivity can be seen in figure 12 and reveal a positive slope indicating that the labor productivity levels of the human capital-poor are in fact in all three surveys below those of the human capital-rich. Moreover, it seems that indeed both groups were able to increase their labor productivity levels, but that the increase for the human capital-poor was less rapid (annual avg. growth rate for the

[71] More specifically, we use three education indicators (adult literacy, adult participation in school, adult years of schooling) and three health indicators (self-reported health problems in the last 14 days, access to improved drinking water sources, access to improved sanitation) to construct our human capital index.

human capital-poor of 2.57% compared to a GRIM of 3.10%) which hence implies a widening of the gap in labor productivity levels between the human capital-poor and -rich. A similar finding is obtained when looking at the corresponding POCs (Type 2) for land productivity (appendix B14) where developments likewise failed to be pro-poor in the relative sense.[72]

Figure 12: Labor productivity opportunity curves (Type 2) for human capital



2.8 Conclusion and policy implications

In the pursuit of sustainable poverty reduction worldwide, pro-poor growth has been identified by many researchers and organizations as probably the most promising pathway to achieve this ambitious goal (e.g. United Nations 2000; World Bank 2000a, b; Ravallion 2001; Klasen 2004; Besley and Cord 2007). Against this background, multiple authors have made suggestions for how pro-poor growth can be measured which has led to the creation of the so-called "pro-poor growth toolbox". The instruments contained in the existing toolbox look at pro-poor growth mainly from the income or the education/health dimension answering the question to what extent the poor in terms of income or education/health were able to benefit from recent developments. However, we argue in this article that the toolbox could be further extended to take account of the crucial importance of the agricultural sector for poverty reduction worldwide (e.g. World Bank 2007; de Janvry and Sadoulet 2010; Valdés and Foster 2010; Christiaensen et al. 2011). We therefore suggest that one can define the poor not only in terms of income or education/health, but also in terms of agricultural productivity and that it is possible by slightly modifying some of the existing tools to account for this agricultural productivity perspective on

[72] Instead of taking human capital as a whole, we also differentiated between the education-poor and -rich and the health-poor and -rich. It turned out that results for human capital are mainly driven by our education indicators and to a smaller extent by the health measures.

poverty. We further emphasized that it is important to recognize that the land and the labor productivity-poor can be different households exhibiting quite different characteristics, so it may be useful to conduct such an analysis separately for both subgroups. The resulting labor/land productivity growth incidence curves (in two versions: monetary and crop-specific) and the labor/land productivity opportunity curves (likewise in two versions) should be seen as complements to the existing toolbox and allow researchers as well as policy makers to gain further insights about who has benefited from recent developments in the country of interest from quite different angles.

This was illustrated for the case of Rwanda using three waves of the nationally representative EICV household surveys. The results for the existing PPG-toolbox indicate that income growth of the poor was relatively faster than for the average, implying that Rwanda successfully achieved pro-poor growth in the weak-absolute and the relative sense. Furthermore, the access of the income-poor to education and health increased impressively in the time period under consideration and this progress was on various occasions even pro-poor according to all three definitions (examples of adult literacy, access to improved sanitation and incidence of illness/injuries). However, room for improvement was identified for the access to improved drinking water sources where the access levels of the (income-) poor only improved marginally.

Turning to the agricultural perspective, the two types of monetary PGICs provided us with first indications that productivity growth of the labor/land productivity-poor was relatively faster than for the labor/land productivity-rich. This finding was confirmed by the three crop-specific land productivity growth incidence curves (for beans, manioc, and maize) which uniformly suggested that productivity growth was not only pro-poor according to the weak-absolute, but also according to the relative definition.[73] Moreover, the productivity opportunity curves (Type 1) revealed lower literacy levels (and slightly higher incidence levels of self-reported illness/injuries) for the labor productivity-poor, thus pointing in the direction that the labor productivity-poor are constrained in their access to social services. However, we observe that both, labor productivity-poor and -rich, were able to improve their education levels considerably between the three surveys and that the gap in literacy levels between the two groups actually decreased slightly. Lastly, the POCs (Type 2) showed that the human capital-poor in fact exhibit considerably lower levels of labor and land productivity compared to the human capital-rich and that their productivity increases were smaller in both, relative and absolute terms. This result appears not

[73] Yet, it is important to emphasize that the rapid increases in agricultural land productivity have to be seen in the Rwandan context with some caution since they may on the one hand indeed be due to efficiency gains by Rwandan farmers, but may on the other hand also be a consequence of a further "bottling-up of labor on the smallest farms" (Byiringiro and Reardon 1996, p. 132).

entirely surprising given the above-discussed broad evidence in the literature of positive effects of improved education/health on agricultural productivity on the micro and the macro level.

Taken together the above results are encouraging in the sense that the Rwandan agricultural sector experienced in the first decade of the 2000s a period with rapid increases in agricultural productivity levels. It appears likely that these successes are to some extent a consequence of the wide array of programs to modernize the agricultural sector that were set up by the Rwandan government as part of the *Rwanda Vision 2020*[74]. While future research may shed further light onto which single interventions worked best in reaching the (productivity-)poor, this analysis has shown that the overall mix of programs led to a situation where productivity-poor households in Rwanda were able to benefit disproportionately (at least in relative terms) from productivity growth.

We conclude with some caveats and further suggestions. First, we are aware of the fact that all data obtained from household interviews (and particularly information on agricultural production) may be prone to considerable measurement and/or recall error which could bias our results. However, we did our best to reduce such measurement error by systematically cleaning the data from outliers at the most disaggregated level possible (i.e. the crop- and item-region-level for the production and the consumption aggregate, respectively) and included various types of plausibility checks. With regard to the existence of a recall bias, it should be noted that a recent article by Beegle et al. (2012) tested this issue empirically coming to the conclusion that the quality of recalled agricultural production data is actually better than expected. Second, we would like to point out that – by definition – the previous analysis cannot prove any kind of causality and it should further be emphasized that many factors have an impact on agricultural productivity for which we did not control in our analysis (e.g. differentials in climate, infrastructure, input use etc.[75]). Nevertheless, we consider the information provided by such a pro-poor analysis as an interesting first step for policy-makers and practitioners in the development field to pursue the question *who* has actually benefited from recent developments in a country. The results may then contribute to improve the targeting of governmental and non-governmental efforts in the field of education, health or agricultural policy. Against the background that Rwanda is in many dimensions in a pioneering role for other SSA countries – being it the introduction of a national health insurance or the increasing scarcity of agricultural

[74] To highlight only a few, one could mention the various crop intensification programmes, the commercialization of crops initiative as well as the erosion protection programmes.

[75] A relatively easy way to account for differentials in location-specific factors such as climate would either be to re-conduct the above analysis on the region-level or to first run a regression of agricultural productivity on climate indicators and then construct the PGICs/POCs using the residual of this regression. Yet, in an attempt not to overload this article, we decided to leave this exercise for future research.

land – the case study provided in this article should further be seen as an opportunity for other SSA countries to learn from the quite successful Rwandan experience over the last years.

Appendix to Chapter 2

Appendix B1: Construction of the consumption aggregate

We included in our consumption aggregate all food purchases, consumption of own produced food, non-food consumption (in line with Deaton and Zaidi (2002) excluding rather "lumpy" expenditures), regular health and education expenses, cost of utilities (such as electricity or drinking water), and wages/transfers/other benefits received in kind (as a counterpart to consumption).[76] For outlier correction, we calculated – in line with NISR (2012) – the natural logarithm of all non-zero consumption values (on a per adult equivalent basis) and identified all those observations as outliers where the observed value was more than 3.5 standard deviations away from the mean value. The identified outliers were then replaced with the mean value for the respective consumption category multiplied with the number of adult equivalents in the household. Given that there may be regional differences in consumption patterns, the above-described outlier correction was not simply done at the item level for food- and non-food consumption but at the item-region level.[77] To take into account differentials in household size and composition, we calculated the number of adult equivalents in each household using equivalence scales that were implemented by FAO already in the 1980s (NISR 2005) and are since then used as the national standard in Rwanda (see appendix B2 for the exact scales). To further adjust for potentially existing economies of scale, we decided to use an exponent of 0.9 for the calculation of the number of adult equivalents.[78]

Appendix B2: Adult equivalence scales

Age groups	**Sex**	
	Male	**Female**
Less than 1 year	0.41	0.41
1 to 3 years	0.56	0.56
4 to 6 years	0.76	0.76
7 to 9 years	0.91	0.91
10 to 12 years	0.97	1.08
13 to 15 years	0.97	1.13
16 to 19 years	1.02	1.05
20 to 39 years	1.00	1.00
40 to 49 years	0.95	0.95
50 to 59 years	0.90	0.90
60 to 69 years	0.80	0.80
More than 70 years	0.70	0.70

[76] We deviate from the approach described in NISR (2012) in excluding the use value of durable goods and the (imputed) rents for the household's dwelling since these are probably the two categories where measurement error is highest (particularly against the background that less than 10% of Rwandan households actually pay rent). Given that such measurement error could severely bias the ranking of households needed for the following pro-poor analysis, we decided to favor reliability of our consumption aggregate over its completeness and hence excluded the two expenditure categories.
[77] Please refer to NISR (2012) for a very good and more detailed description of the outlier correction procedure used.
[78] This represents another difference to the methodology used by NISR (2012) who do not directly account for economies of scale in a household.

Appendix B3: Levels of contemplated income and non-income indicators for Rwanda (based on EICV1-EICV3 – ag. population only)

Indicator	**Survey**	**Tool**	**Unit**	**Mean of decile… (cumulated in case of opportunity curves)**										**10:1 Ratio**	**Gini**
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
Avg. household expenditures per a.e.	EICV1	GIC	RWF	22,459	31,022	38,322	45,123	53,551	63,238	74,342	90,601	113,051	182,838	8.14	0.34
Avg. household expenditures per a.e.	EICV2	GIC	RWF	25,647	35,306	43,403	50,852	58,955	68,656	80,557	97,165	123,857	201,642	7.86	0.33
Avg. household expenditures per a.e.	EICV3	GIC	RWF	32,433	42,635	51,223	59,673	69,183	79,520	92,156	110,068	137,547	215,365	6.64	0.31
Avg. literacy rate (aged 15+)	EICV1	OC	%	36.08	38.68	41.15	42.58	43.76	44.97	46.26	47.62	48.52	49.42		
Avg. literacy rate (aged 15+)	EICV2	OC	%	44.22	48.94	51.18	52.86	54.47	55.51	56.93	58.37	59.66	60.97		
Avg. literacy rate (aged 15+)	EICV3	OC	%	54.59	57.07	58.20	59.65	60.44	61.32	62.13	63.05	63.71	64.60		
Avg. years of schooling (aged 15+)	EICV1	Cond. NIGIC	years	1.39	1.73	1.89	1.99	2.12	2.23	2.53	2.68	2.66	3.13	2.25	0.49
Avg. years of schooling (aged 15+)	EICV2	Cond. NIGIC	years	2.10	2.55	2.81	3.03	3.13	3.24	3.56	3.73	3.80	4.49	2.14	0.37
Avg. years of schooling (aged 15+)	EICV3	Cond. NIGIC	years	2.74	3.09	3.23	3.40	3.40	3.53	3.73	3.90	4.06	4.64	1.69	0.34
Avg. years of schooling (aged 15+)	EICV1	Uncond. NIGIC	years	0.00	0.00	0.31	1.15	1.74	2.22	2.79	3.41	4.47	6.29	n.d.	0.49
Avg. years of schooling (aged 15+)	EICV2	Uncond. NIGIC	years	0.01	0.88	1.68	2.23	2.83	3.27	3.99	4.75	5.60	7.23	866.54	0.37
Avg. years of schooling (aged 15+)	EICV3	Uncond. NIGIC	years	0.07	1.19	2.04	2.73	3.17	3.78	4.33	5.03	5.82	7.58	112.43	0.34
Access to improved sanitation	EICV1	OC	%	31.25	35.08	36.53	37.94	40.05	41.91	43.57	44.46	45.79	47.95		
Access to improved sanitation	EICV2	OC	%	40.51	43.66	47.15	49.61	50.48	51.75	52.23	53.32	54.97	56.70		
Access to improved sanitation	EICV3	OC	%	66.54	68.41	70.59	71.65	71.80	72.23	72.64	73.09	73.55	74.49		
Access to improved drinking water	EICV1	OC	%	68.60	68.82	69.43	68.83	69.30	68.62	68.35	67.51	67.67	67.86		
Access to improved drinking water	EICV2	OC	%	67.07	66.70	66.26	66.50	67.01	67.16	67.46	66.82	67.30	68.16		
Access to improved drinking water	EICV3	OC	%	70.77	69.31	70.11	70.34	70.49	70.88	71.14	71.04	71.29	72.12		
Health problems in the last 14 days	EICV1	OC	%	30.64	28.94	28.15	27.91	28.35	28.12	28.13	28.17	28.16	28.51		
Health problems in the last 14 days	EICV2	OC	%	20.29	19.73	19.94	20.48	20.69	20.70	20.81	20.92	21.33	21.68		
Health problems in the last 14 days	EICV3	OC	%	18.62	18.15	18.08	18.24	18.66	18.82	18.77	18.78	19.07	19.15		
Avg. production per ha (all crops)	EICV1	PGIC	RWF	49,772	89,697	133,640	186,809	249,922	331,858	436,067	611,754	898,863	1,571,304	31.57	0.50
Avg. production per ha (all crops)	EICV2	PGIC	RWF	78,627	134,449	190,784	254,092	329,866	421,585	538,568	694,717	954,293	1,504,059	19.13	0.44
Avg. production per ha (all crops)	EICV3	PGIC	RWF	123,861	191,524	252,814	316,001	387,544	466,052	559,423	685,373	883,049	1,305,331	10.54	0.36
Avg. production per worker (all crops)	EICV1	PGIC	RWF	8,860	19,070	28,536	40,600	54,643	71,954	95,460	132,472	193,640	357,951	40.40	0.51
Avg. production per worker (all crops)	EICV2	PGIC	RWF	14,203	28,830	43,729	58,909	77,253	98,570	127,278	167,351	236,694	432,834	30.47	0.48
Avg. production per worker (all crops)	EICV3	PGIC	RWF	20,842	38,652	54,315	70,574	89,215	112,344	141,360	182,408	252,612	441,029	21.16	0.45
Avg. production per ha (beans only)	EICV1	PGIC	kg	32.43	63.93	100.33	143.81	189.11	242.12	313.67	427.20	607.91	1,122.74	34.62	0.50
Avg. production per ha (beans only)	EICV2	PGIC	kg	46.09	92.97	138.45	188.85	249.48	326.19	426.19	562.43	806.19	1,360.88	29.53	0.48
Avg. production per ha (beans only)	EICV3	PGIC	kg	90.81	179.33	259.51	341.19	433.29	541.34	673.05	856.79	1,140.02	1,769.10	19.48	0.42
Avg. production per ha (manioc only)	EICV1	PGIC	kg	89.34	182.33	285.63	414.56	602.08	874.52	1,252.60	2,057.09	3,357.94	7,174.36	80.31	0.61
Avg. production per ha (manioc only)	EICV2	PGIC	kg	136.44	304.92	524.57	793.89	1,099.11	1,567.76	2,297.46	3,347.99	5,052.95	10,268.72	75.26	0.58
Avg. production per ha (manioc only)	EICV3	PGIC	kg	188.27	370.75	570.10	785.38	1,039.95	1,364.93	1,830.16	2,460.35	3,569.74	6,711.50	35.65	0.51

Note: The abbreviation "n.d." stands for not defined and is used in cases where one would have to divide by zero to obtain the 10:1 ratio.

Appendix B3 (ctd.): Levels of contemplated income and non-income indicators for Rwanda (based on EICV1-EICV3 – ag. population only)

Indicator	Survey	Tool	Unit	Mean of decile... (cumulated in case of opportunity curves)										10:1 Ratio	Gini
				1	2	3	4	5	6	7	8	9	10		
Avg. production per ha (maize only)	EICV1	PGIC	kg	30.97	62.86	93.41	130.40	178.18	236.23	312.10	427.50	674.93	1,382.95	44.65	0.54
Avg. production per ha (maize only)	EICV2	PGIC	kg	39.06	74.84	118.84	165.65	223.15	304.85	408.40	566.81	879.23	1,686.15	43.17	0.54
Avg. production per ha (maize only)	EICV3	PGIC	kg	80.15	156.14	234.55	322.76	435.14	562.58	736.75	978.19	1,343.29	2,298.70	28.68	0.47
Avg. literacy rate (aged 15+)	EICV1	Land POC - Type 1	%	48.19	49.51	48.62	49.16	49.65	49.88	49.91	49.79	49.91	50.36		
Avg. literacy rate (aged 15+)	EICV2	Land POC - Type 1	%	56.27	56.75	57.73	58.19	58.96	59.85	60.11	60.22	60.51	61.15		
Avg. literacy rate (aged 15+)	EICV3	Land POC - Type 1	%	62.02	61.79	61.62	62.72	63.06	63.58	63.90	64.30	64.41	64.88		
Health problems in the last 14 days	EICV1	Land POC - Type 1	%	28.14	28.29	28.02	27.67	28.38	28.12	27.79	27.95	28.12	28.10		
Health problems in the last 14 days	EICV2	Land POC - Type 1	%	22.60	21.94	21.62	21.50	21.51	21.08	20.97	21.10	21.36	21.23		
Health problems in the last 14 days	EICV3	Land POC - Type 1	%	19.00	19.78	19.79	19.58	19.54	19.43	19.23	19.21	19.26	19.02		
Avg. literacy rate (aged 15+)	EICV1	Labor POC - Type 1	%	40.17	41.83	42.94	44.59	45.50	46.40	46.98	47.68	48.30	49.42		
Avg. literacy rate (aged 15+)	EICV2	Labor POC - Type 1	%	50.12	52.19	53.18	53.61	55.12	56.51	57.60	58.35	59.39	60.97		
Avg. literacy rate (aged 15+)	EICV3	Labor POC - Type 1	%	57.44	58.62	58.66	58.99	59.27	60.26	61.42	62.27	63.37	64.60		
Health problems in the last 14 days	EICV1	Labor POC - Type 1	%	30.46	29.46	29.11	28.84	28.68	28.45	28.60	28.33	28.45	28.51		
Health problems in the last 14 days	EICV2	Labor POC - Type 1	%	25.05	23.46	23.37	23.22	23.25	22.92	22.60	22.17	21.96	21.68		
Health problems in the last 14 days	EICV3	Labor POC - Type 1	%	21.62	21.04	21.18	21.02	20.99	20.67	20.17	19.73	19.42	19.15		
Avg. production per ha (all crops)	EICV1	Land POC - Type 2 (human cap.)	RWF	442,904	434,959	440,163	447,372	440,360	437,734	444,318	445,286	450,072	455,675		
Avg. production per ha (all crops)	EICV2	Land POC - Type 2 (human cap.)	RWF	436,720	445,410	464,638	472,891	481,437	484,589	494,017	494,835	503,306	509,828		
Avg. production per ha (all crops)	EICV3	Land POC - Type 2 (human cap.)	RWF	480,389	485,797	494,335	501,150	504,498	504,628	509,100	510,735	514,575	516,841		
Avg. production per worker (all crops)	EICV1	Labor POC - Type 2 (human cap.)	RWF	84,997	83,747	84,290	85,838	86,883	88,392	91,540	93,864	96,549	100,272		
Avg. production per worker (all crops)	EICV2	Labor POC - Type 2 (human cap.)	RWF	99,244	95,226	100,408	104,100	106,408	109,677	113,718	116,193	121,461	128,484		
Avg. production per worker (all crops)	EICV3	Labor POC - Type 2 (human cap.)	RWF	110,907	109,957	115,100	119,586	122,804	125,482	128,921	130,489	134,937	140,338		

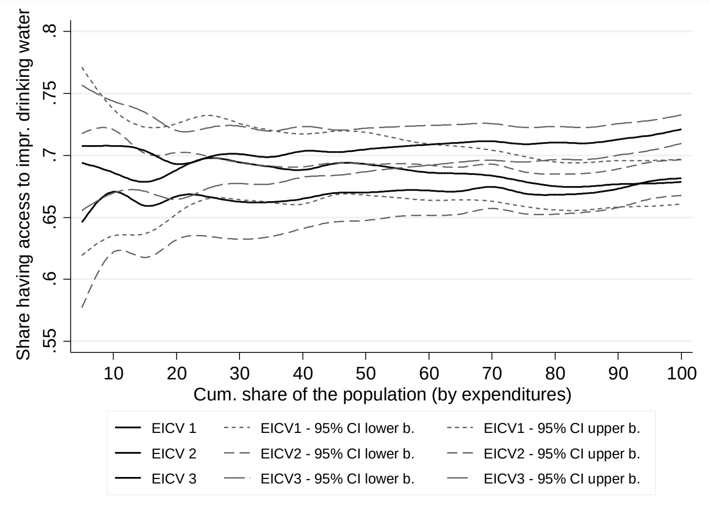
Note: The abbreviation "n.d." stands for not defined and is used in cases where one would have to divide by zero to obtain the 10:1 ratio.

Appendix B4: Pro-poor growth rates and growth rates in the mean for Rwanda (based on EICV1-EICV3 – agrarian population only)

Indicator	**Tool**	**Reference period**	**Ann. growth rate in the mean (%)**	**Avg. annual growth rate for the poorest... (in %)**						**Abs. increase in the mean**	**Abs. increase for the poorest...**					
				5%	**10%**	**15%**	**20%**	**25%**	**100%**		**5%**	**10%**	**15%**	**20%**	**25%**	**100%**
Avg. household expenditures per a.e.	GIC	EICV1-EICV3	2.02	3.56	3.42	3.29	3.18	3.09	2.32	17,538	9,295	9,968	10,431	10,793	11,143	17,527
Avg. literacy rate (aged 15+)	OC	EICV1-EICV3	2.47	4.71	3.88	3.90	3.65	3.45	2.54	15.18	21.54	18.51	19.11	18.39	17.79	15.18
Avg. years of schooling (aged 15+)	Cond. NIGIC	EICV1-EICV3	4.35	6.72	6.37	5.98	5.89	5.69	4.50	1.34	1.34	1.35	1.33	1.35	1.35	1.34
Avg. years of schooling (aged 15+)	Uncond. NIGIC	EICV1-EICV3	4.35	n.d.	n.d.	n.d.	n.d.	n.d.	5.18	1.34	0.00	0.07	0.35	0.63	0.88	1.34
Access to improved sanitation	OC	EICV1-EICV3	4.09	8.55	7.24	6.22	6.43	6.60	4.32	26.54	38.65	35.29	31.89	33.33	34.81	26.54
Access to improved drinking water	OC	EICV1-EICV3	0.55	0.17	0.28	0.33	0.07	0.01	0.56	4.25	1.34	2.17	2.52	0.49	0.07	4.25
Health problems in the last 14 days	OC	EICV1-EICV3	-3.55	-5.80	-4.36	-4.37	-4.11	-3.95	-3.54	-9.36	-16.57	-12.02	-11.50	-10.79	-10.33	-9.36
Avg. production per ha (all crops)	PGIC	EICV1-EICV3	1.15	9.37	8.78	8.35	7.98	7.65	3.58	61,313	65,764	74,112	81,485	87,971	93,631	61,138
Avg. production per worker (all crops)	PGIC	EICV1-EICV3	3.10	9.18	8.42	7.85	7.53	7.30	4.60	40,047	9,461	11,985	13,854	15,791	17,611	40,019
Avg. production per ha (beans only)	PGIC	EICV1-EICV3	6.24	9.26	9.70	9.81	9.77	9.62	7.61	305.46	41.33	58.31	73.21	86.82	98.98	304.43
Avg. production per ha (manioc only)	PGIC	EICV1-EICV3	1.47	7.22	7.06	7.01	6.88	6.81	4.09	279.70	73.55	98.92	122.79	143.88	166.72	259.58
Avg. production per ha (maize only)	PGIC	EICV1-EICV3	6.63	8.82	8.99	8.90	8.81	8.79	7.89	361.30	36.01	49.23	60.40	71.26	82.63	360.43
Avg. production per ha (maize only)	PGIC	EICV1-EICV2	4.02	4.66	4.10	3.66	3.52	3.58	4.08	93.88	7.39	8.15	8.70	10.11	12.36	92.91
Avg. literacy rate (aged 15+)	Land POC (Type 1)	EICV1-EICV3	2.33	1.96	2.33	2.12	2.04	2.26	2.34	14.52	12.04	13.83	12.71	12.28	13.38	14.52
Health problems in the last 14 days	Land POC (Type 1)	EICV1-EICV3	-3.49	-3.43	-3.50	-3.16	-3.21	-3.07	-3.48	-9.08	-8.66	-9.13	-8.38	-8.52	-8.15	-9.08
Avg. literacy rate (aged 15+)	Labor POC (Type 1)	EICV1-EICV3	2.47	2.96	3.33	3.34	3.13	2.97	2.48	15.18	16.38	17.27	17.73	16.79	16.00	15.18
Health problems in the last 14 days	Labor POC (Type 1)	EICV1-EICV3	-3.55	-3.48	-3.02	-3.06	-2.99	-2.99	-3.58	-9.36	-11.00	-8.84	-8.74	-8.42	-8.42	-9.36
Avg. production per ha (all crops)	Land POC (Type 2) (by human capital)	EICV1-EICV3	1.15	0.85	0.74	1.00	1.02	1.10	1.18	61,138	41,832	37,485	49,160	50,838	55,444	61,167
Avg. production per worker (all crops)	Labor POC (Type 2) (by human capital)	EICV1-EICV3	3.10	0.90	2.53	2.73	2.57	2.74	3.11	40,065	9,999	25,910	27,419	26,211	28,389	40,066

Note: The abbreviation "n.d." stands for not defined and is used in cases where one would have to divide by zero to obtain the annual growth rate.

Appendix B5: Opportunity curves for access to improved drinking water



Appendix B6: Comparison of land and labor productivity-poor households (based on EICV1)

Indicator	**Land productivity poor households**	**s.e.**	**Labor productivity poor households**	**s.e.**
Total consumption per ae	79,487	(6,969)	58,083	(1,816)
Ag. productivity per ha	67,230	(867.7)	175,088	(8,557)
Ag. productivity per worker	41,474	(1,507)	13,385	(201.8)
Total size of plots (in hectares)	1.27	(0.043)	0.45	(0.020)
Household size	4.81	(0.086)	5.12	(0.099)
Number of farmers	2.17	(0.044)	2.65	(0.056)
Literacy rate (aged 15+)	49.51	(1.422)	43.22	(1.511)
Years of schooling (aged 15+)	2.16	(0.071)	1.74	(0.068)
Access to impr. sanitation	45.82	(1.881)	44.25	(2.164)
Access to impr. drinking water	66.78	(1.778)	68.76	(2.010)
Health problems in the last 2 weeks	28.31	(1.080)	28.79	(1.203)

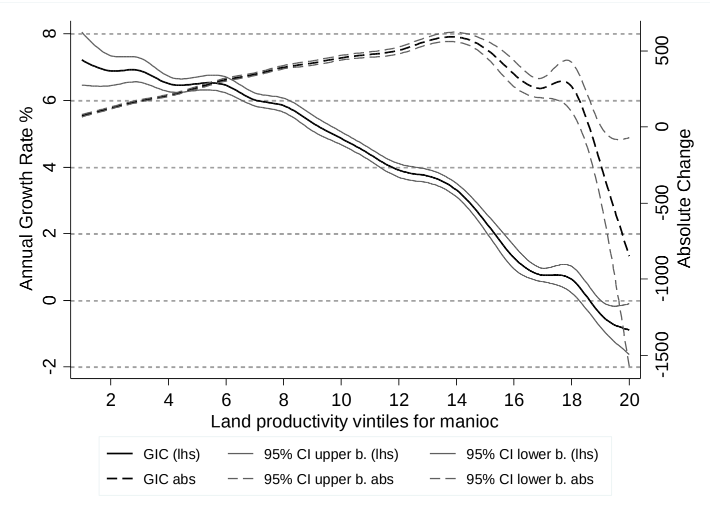
Appendix B7: Comparison of land and labor productivity-poor households (based on EICV3)

Indicator	**Land productivity poor households**	**s.e.**	**Labor productivity poor households**	**s.e.**
Total consumption per ae	90,301	(2,586)	83,704	(2,368)
Ag. productivity per ha	153,601	(981.3)	314,848	(6,358)
Ag. productivity per worker	87,236	(2,281)	28,664	(251.6)
Total size of plots (in hectares)	0.97	(0.026)	0.28	(0.007)
Household size	4.73	(0.055)	4.56	(0.060)
Number of farmers	1.72	(0.024)	2.01	(0.023)
Literacy rate (aged 15+)	61.79	(0.882)	58.51	(0.934)
Years of schooling (aged 15+)	3.41	(0.053)	3.08	(0.049)
Access to impr. sanitation	76.67	(1.026)	70.72	(1.228)
Access to impr. drinking water	69.28	(1.066)	72.87	(1.095)
Health problems in the last 2 weeks	19.77	(0.678)	21.08	(0.772)

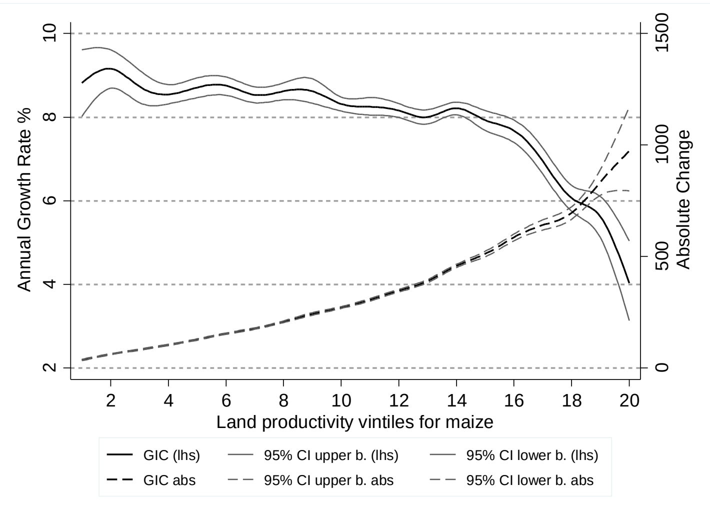
Appendix B8: Share of land used by major crops in total active agricultural land

Crop	EICV1	EICV2	EICV3
Beans	27.18%	28.32%	21.70%
Corn	8.18%	10.76%	11.47%
Manioc	10.25%	9.89%	12.76%
Peas	1.45%	1.82%	1.32%
Potatoes	7.11%	6.25%	5.55%
Sorghum	11.37%	12.39%	7.64%
Soy	1.85%	2.29%	1.36%
Sweet potatoes	12.69%	12.30%	8.74%
Taro	1.77%	1.41%	2.08%
Various types of bananas	10.57%	6.96%	18.25%
Other	7.57%	7.61%	9.14%

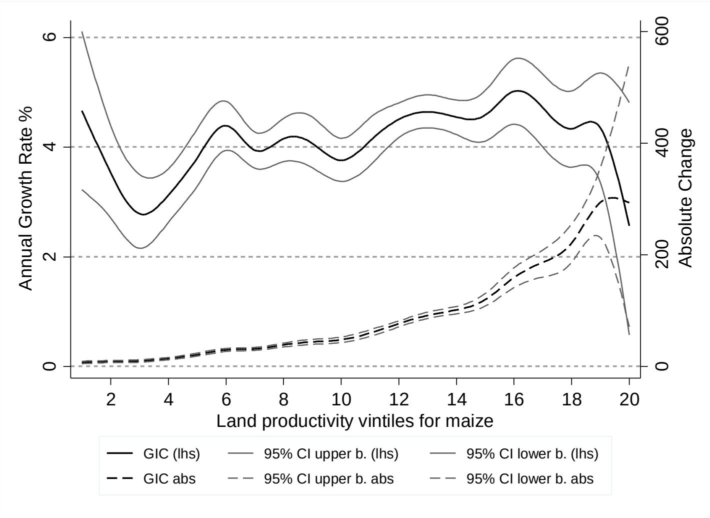
Appendix B9: Land productivity growth incidence curves for manioc: EICV1-EICV3



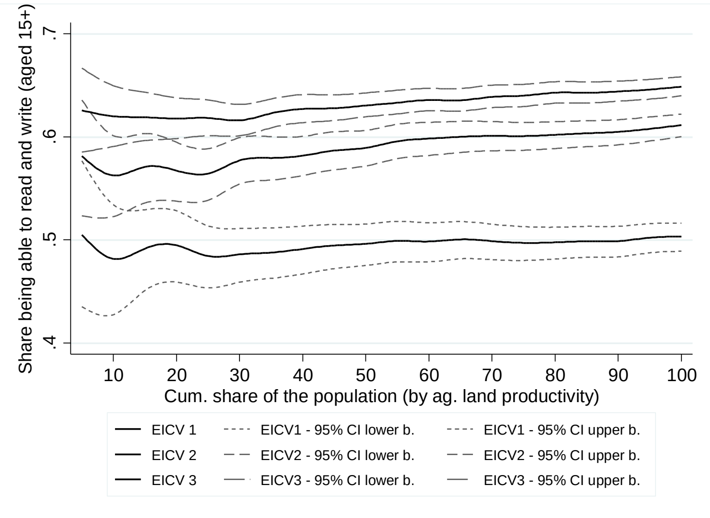
Appendix B10: Land productivity growth incidence curves for maize: EICV1-EICV3



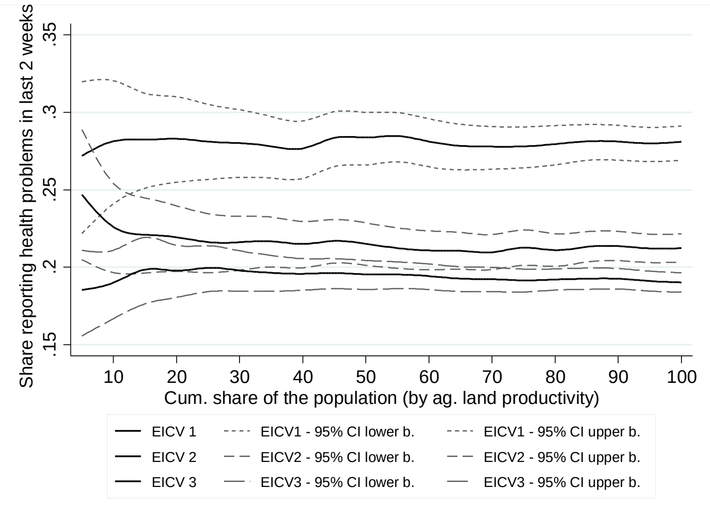
Appendix B11: Land productivity growth incidence curves for maize: EICV1-EICV2



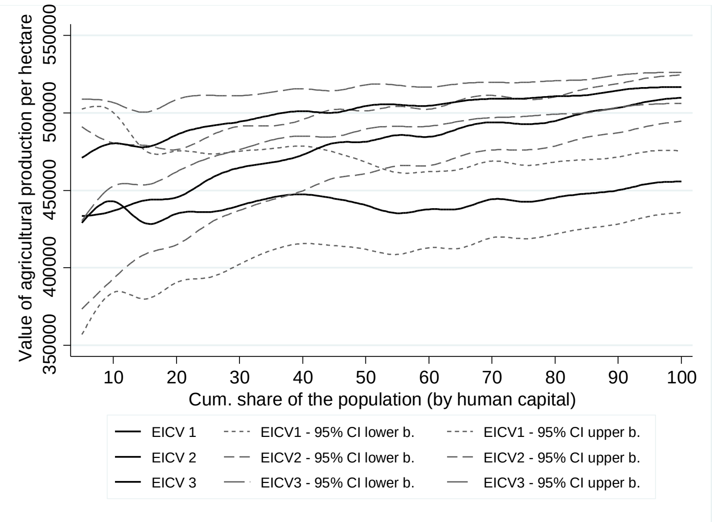
Appendix B12: Land productivity opportunity curves (Type 1) for adult literacy (aged 15+)



Appendix B13: Land productivity opportunity curves (Type 1) for health problems in the last two weeks



Appendix B14: Land productivity opportunity curves (Type 2) for human capital



3. Chapter

Livestock as an Imperfect Buffer Stock in Poorly Integrated Markets[79]

with Simon Lange

Abstract

Livestock holdings in rural areas of the West African Semi-arid Tropics (WASAT) are often substantial yet there is little evidence for precautionary saving in the form of livestock out of transitory income. The present paper re-visits farm households' ability to smooth consumption *ex-post* via savings in the form of livestock. Exploiting two comprehensive panel datasets covering Burkina Faso's 2004 drought, we find that livestock sales increase significantly in response to drought. Consistent with consumption smoothing, the motive frequently cited by households for these extra sales is the need to finance food consumption. Using deviations in rainfall to extract the transitory component of crop profit, we find evidence that shocks are nevertheless to a large extent passed on to consumption expenditure. In line with the literature, our results suggest that some consumption smoothing is achieved via adjustments to grain stocks while households apparently fail to smooth consumption by adjusting livestock holdings. We argue that this seemingly contradictory finding is largely due to a decrease in relative livestock prices during droughts. This suggests that selling livestock is a costly coping strategy which may be the reason why households rely on it only to a limited extent.

3.1 Introduction

The theory of optimal savings in the absence of formal insurance mechanisms and credit markets predicts that households facing covariate risks will use liquid assets for self-insurance (e.g. Deaton 1990, 1991). Understanding whether and how households are able to smooth consumption in the event of adverse income shocks is of great importance. Fafchamps and Pender (1997), for instance, argue that the need to hold precautionary savings may generate a poverty trap by preventing poor agents from undertaking profitable investments that are, in principle, viable. In a similar direction, Zimmerman and Carter (2003) show that subsistence constraints and a need to smooth incomes in the absence of insurance can generate poverty traps in which poor households hold defensive asset portfolios and thus forgo higher expected returns. If

[79] The authors would like to thank Kimseyinga Savadogo, Denis Akouwerabou and Omer Combary of the University of Ouagadougou and the Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutique de Burkina Faso for granting them access to the PNGT and EPA datasets, respectively. In addition, the authors are grateful to Stephan Klasen, Joachim von Braun, Hermann Waibel, participants at the AEL Conference 2014 in Passau, and seminar participants in Göttingen for their valuable comments.

consumption smoothing via asset accumulation is costly, this would strengthen the case for governments to intervene in order to correct market failures.

It has long been hypothesized that one of the major buffer stocks in rural areas of developing countries is livestock. However, empirical studies investigating households' responses to adverse shocks are inconclusive. Based on data from India and war-time Rwanda, Rosenzweig and Wolpin (1993) and Verpoorten (2009) find that households increase sales of livestock during droughts and episodes of civil conflict, respectively. In contrast, Fafchamps, Udry, and Czukas (1998), Kazianga and Udry (2006), and Carter and Lybbert (2012) find no evidence that households are able to generate additional revenues via sales based on data covering a drought in rural Burkina Faso.

It is important to recognize that these two strands of the literature actually pursue two slightly differentiated questions which are both, however, related to distress sales:

1. Do households increase (net) sales of livestock in times of economic hardship (e.g. droughts, conflict)?
2. Does net saving in the form of livestock vary positively with transitory income, i.e. do households generate additional revenues for consumption from sales of livestock in times of adverse income shocks?

The difference between the above questions lies in the role assumed by price movements. If prices were constant, the answer to both questions would always be the same. If, however, livestock prices varied positively with transitory income, which is to be expected when markets are poorly integrated and shocks are correlated across households, an increase in net sales would not necessarily translate into an increase in revenues. The above studies differ in which of the two questions they address: while Rosenzweig and Wolpin (1993) and Verpoorten (2009) find evidence for an increase in sales in response to adverse shocks, studies that focus on precautionary savings typically find no relationship between savings in the form of livestock and transitory income.

Instead of investigating only one of the above questions in isolation, as previous studies have done, this paper addresses both questions at the same time in order to explain the apparent contradiction. We employ two large panel datasets from Burkina Faso that cover the harvests of 2003 and 2004 as well as 2004–2007, respectively, which saw considerable variation in rainfall including a drought in 2004.

Our findings with regard to the first question suggest that livestock sales increase in response to adverse rainfall shocks at the level of provinces with no off-setting increase in purchases. Based on count data models, we also find that sales are negatively related to rainfall at the household-level. Consistent with a need to compensate for a decrease in revenues from cropping, households cite food consumption as the main motive for extra sales.

We then turn to the second question and ask whether households save in the form of livestock out of transitory crop profit based on an empirical strategy that identifies the transitory component of crop profit from unanticipated variation in rainfall. Our framework shares key components with specifications typically employed in the literature and results in similar findings. A large portion of transitory income is transmitted to consumption expenditure. There is no evidence for an important role of net sales of livestock in consumption smoothing, whereas adjustments to grain stocks are sizeable. We also show that in our sample, this finding is not driven by behavioral differences between subgroups differentiated by livestock holdings as was suggested recently by Carter and Lybbert (2012).

Viewed in isolation, our results are largely in line with previous findings in the literature and beg the question of why there are additional sales yet no additional revenues. We argue that prices account for this puzzle: in a province-level panel dataset, we show that cattle prices decline in the event of an adverse weather shock in both nominal and real terms. This is consistent with an increase in net sales in markets that are not fully integrated and potentially explains the lack of correlation between transitory income and net purchases of livestock in monetary terms: an increase in the net number of animals sold is offset by a decrease in livestock prices. This renders adjustments to livestock holdings a costly strategy to smooth consumption. It also explains why households bear consumption cuts despite livestock holdings that would allow them to completely offset transitory income losses. At least some households will find that post-shock prices are too low for their livestock and hence abstain from selling.

In addition to contributing to the empirical literature on asset-based consumption smoothing under uncertainty and credit constraints (Rosenzweig and Wolpin 1993; Fafchamps, Udry, and Czukas 1998; Zimmerman and Carter 2003; Kazianga and Udry 2006; Park 2006; Verpoorten 2009; Carter and Lybbert 2012), this paper is also related to a recent literature on intra-temporal arbitrage decisions by farmers in developing countries (e.g. Barrett 2007; Stephens and Barrett 2011; Burke 2014). We find that livestock sales are negatively related to prices which, in turn, are driven by weather shocks. If borrowing opportunities were available, at least some farmers should be observed taking advantage of such fluctuations by purchasing livestock during droughts. The above studies show that farmers do not take advantage of arbitrage opportunities resulting from intra-seasonal variation in grain prices and suggest that a lack of borrowing opportunities account for this.

The paper proceeds as follows: section 3.2 reviews the relevant literature and explains the setting of our empirical investigation. Section 3.3 introduces and compares datasets used in this study. Section 3.4 provides some descriptive evidence on behavioral responses to the drought in 2004. We show that crop output declined substantially and that the proportion of households reporting consumption cuts increased following the 2004 drought. In section 3.5, we show that sales at the province-level increase in response to adverse rainfall and that there is no off-setting change in purchases. We also detect a corresponding relationship at the household-level. Section 3.6 details the empirical strategy to identify the effects of transitory crop profit on consumption and savings in the form of grain storage and net purchases of livestock and presents our results. Section 3.7 investigates the price response to adverse rainfall and problems that this finding potentially poses to microeconometric investigations of consumption smoothing. Section 3.8 concludes and discusses policy implications.

3.2 Background

3.2.1 Literature review

The canonical model of saving under credit-constraints and uncertainty over future income suggests that precaution is one motive of risk-averse agents for holding assets (Deaton 1990, 1991; Fafchamps, Udry, and Czukas 1998). In fact, for a high enough discount rate, it is the only motive for holding wealth (Deaton 1992) and for large enough wealth, consumption is proportional to permanent income (e.g. Zeldes 1989). This further suggests that poor households will smooth consumption via adjusting buffer stocks as they are more likely to be credit-constrained. In line with this view, poor households in developing countries are usually found to hold considerable amounts of extra saving, for instance, in the form of grain stocks, livestock or other liquid assets such as jewelry (Rosenzweig and Wolpin 1993; Park 2006).[80]

The West African Semi-arid Tropics, which have been the site of recurring droughts for as much as three millennia (Shanahan et al. 2009), are an ideal setting for researchers to study households' responses to shocks in terms of adjustments to buffer stocks. The set of strategies to cope with drought-induced shortfalls in income resident households can choose from is severely limited.

[80] Jewelry has been shown to be important primarily in the Indian context (Rosenzweig and Wolpin 1993). Cash holdings are assumed to be important but hardly ever recorded by household surveys.

Despite substantial risks (e.g. Carter 1997), households typically lack access to formal insurance mechanisms (Binswanger and Rosenzweig 1986; Binswanger and McIntire 1987). Informal insurance arrangements that do not extend beyond villages are ineffective as adverse shocks are to a large extent covariate as nearly all households depend on rain-fed agriculture (Carter 1997).

Livestock in particular has long been thought of as the main buffer stock in this setting (Binswanger and McIntire 1987; Reardon, Matlon, and Delgado 1988). Binswanger and McIntire (1987) argue that animals are more resistant to droughts as there might still be vegetative growth that provides fodder and that animals can be shifted to neighboring areas in case of local droughts. Animal husbandry was thus hypothesized to be associated with less production risk. Storage of grain, on the other hand, is expensive as stocks exhibit limited durability and are often affected by pests. There should thus be an upper bound to what households are willing to hold in storage (ibid.).

Early anthropological and economic case studies set in the WASAT region initially seemed to support the claim that livestock sales[81] are an important mechanism to smooth consumption. Watts (1983), for instance, documents that Hausa farmers in northern Nigeria sold livestock in the aftermath of the drought in the early 1970s. Similarly, Swinton (1988) documents that farmers in Niger liquidated livestock in response to the 1984 drought in order to pay for food.

A theoretical model that captures relevant characteristics of households' savings decision in this region is presented by Fafchamps, Udry, and Czukas (1998). They model portfolio choices of risk-averse households in a dynamic setting with uncertainty over future incomes from farming. Liquid wealth is composed solely of stored grain and livestock, where the latter exhibits higher returns. This model suggests that livestock holdings are an increasing function of returns to livestock and losses associated with grain storage and a decreasing function of the (real) purchase price of cattle, livestock's labor requirements, the correlation between crop and livestock returns, risk aversion, and the variance of livestock returns. Since most households are believed to exhibit either constant or decreasing relative risk aversion, the authors conjecture that livestock holdings constitute a constant or increasing proportion of liquid wealth. The model thus predicts that livestock will be liquidated in response to an adverse income shock. If households have decreasing relative risk aversion, households will liquidate livestock overproportionately as portfolios are adjusted.

[81] Several studies find that killing livestock for meat is rare in this region. Livestock is usually sold and the proceeds used to purchase grain (e.g. Loutan 1985).

For empirical investigations of the role of livestock in the WASAT region, Fafchamps, Udry, and Czukas (1998) and subsequent authors used the ICRISAT data from Burkina Faso that incidentally covered the early 1980s drought (Fafchamps, Udry, and Czukas 1998; Kazianga and Udry 2006; Carter and Lybbert 2012). Surprisingly, these studies fail to confirm an important role of livestock sales in *ex-post* consumption smoothing. Indeed, Fafchamps, Udry, and Czukas (1998) report that if livestock is sold in times of adverse income shocks, the financing of consumption expenditure is by far the most important motive. However, regressing revenues from net sales of livestock on different measures of income shocks, the authors find that at most 30 percent of an unanticipated shortfall in income at the village-level is compensated in the form of asset sales. The actual figure, they reason, could be much closer to 15 percent.

A similar result emerges in Kazianga and Udry (2006) who also test for consumption smoothing directly. They conclude that "[n]one of the main risk coping strategies [...] hypothesized in the literature were effective during the crisis period [...]." To the contrary, they report that about 55 percent of changes in transitory income were passed onto consumption, a pattern entirely incompatible with the permanent income hypothesis. As in Fafchamps, Udry, and Czukas (1998), they find a negligible role for livestock as a buffer yet a considerable role for grain stocks. Adding even further to the puzzle, livestock holdings reported by households after the drought were often large enough to have compensated entirely for the shortfall in consumption and the observed lack of consumption smoothing does not seem to have been driven by indivisibilities (Kazianga and Udry 2006). A final empirical study based on these data is Carter and Lybbert (2012). The authors argue that only households with large livestock holdings engage in consumption smoothing via adjustments to these holdings. However, for the vast majority of households, they find no savings in the form of livestock out of transitory income.

On the other hand, studies in different settings have found evidence for distress sales of livestock. In particular, Rosenzweig and Wolpin (1993) demonstrate convincingly that sales of bullocks play a crucial role in Indian farmers' strategies to smooth consumption. They show that bullocks account for a large share of households' wealth, are bought and sold in well-developed, inter-regional markets, and are sold even when profit realizations are low. More recently, Verpoorten (2009) who studies retrospective reports of livestock sales during Rwanda's genocide, finds that almost half of all cattle sales in 1994 were motivated by war-induced food shortages. Interestingly, households resorted to this coping strategy despite prices having fallen to about 50 percent of their pre-genocide level.

Of course, conditions in India's rural economy as well as circumstances in wartime Rwanda may differ in important aspects from conditions in the WASAT region. It may thus be plausible that region-specific factors change households' coping strategies. In the Rosenzweig and Wolpin-study, for instance, the authors find that markets are fairly well integrated and that livestock prices are therefore insulated from village-level shocks, a condition that cannot be easily maintained for most of the WASAT.

In this paper we argue that it is important to recognize that the above studies arrive at different conclusions also because they pursue related yet different questions. While the former studies set in Burkina Faso, in one form or the other, investigate the relationship between crop profit and revenues from livestock sales, the latter studies from India and Rwanda pursue the question whether livestock sales *in quantities* increase in the event of a shock.

Both questions are, of course, inter-related and both contribute to our understanding of coping behavior. It is nevertheless important to be clear about the differences. Smoothing consumption via livestock sales and purchases is going to be less effective if it is counter-cyclical, i.e. if households sell livestock when prices are low. For instance, it is unclear whether studies that find a role for livestock sales – particularly Verpoorten (2009) who finds massive sales at very low prices – also would have found a positive effect on revenues from sales. Our study is, to our knowledge, the first to investigate both questions at the same time.

The reason why relative livestock prices decline in times of drought are, of course, found in general equilibrium-effects. If shocks are spatially correlated, many households will find it necessary to sell livestock in order to generate revenues at the same time. This will lead to a drop in prices if markets for livestock are only poorly integrated, i.e. if the demand schedule for livestock that households face in a given locality is downward sloping. This, in turn, will be the case if, for instance, transport costs are high.

It seems likely that markets in Burkina Faso match this description. There is some evidence that in Niger, a country bordering Burkina Faso to the Northeast, markets for livestock are poorly integrated (Fafchamps and Gavian 1997). This study nevertheless finds that relative prices respond to changes in urban meat demand, signaling at least some degree of integration. We show below that cattle prices in Burkina Faso are responsive to rainfall levels. At the same time, observed sales in a given province do not move in lockstep with purchases, suggesting some outward links.

While mainly ignored in the empirical literature, price effects have featured in several theoretical contributions. Fafchamps, Udry, and Czukas (1998) acknowledge that livestock is less liquid than commonly assumed but do not investigate this possibility further. This is done by Zimmerman and Carter (2003) who extend the model by Fafchamps, Udry, and Czukas (1998) in several interesting ways. Again, it is assumed that households choose between two different assets, one productive (livestock) and one unproductive yet safe (e.g. grain stocks). The productive asset is associated with higher expected returns yet more volatility since prices are determined locally and incomes are subject to covariate shocks. Hence, local asset prices might react to covariate shocks; the high-yielding asset is associated with additional price risk. Finally, it is assumed that agents see their subsistence at risk.

Simulating this model based on parameters estimated from the Burkinabe ICRISAT data, Zimmerman and Carter find that households' portfolio strategies quickly bifurcate in this kind of model. Agents initially endowed with less wealth adopt a defensive strategy characterized by a lower portfolio value and by a less productive mix of assets. Agents endowed with more wealth, on the other hand, adopt a much more offensive strategy, holding only a negligible share of their liquid wealth in the form of the low-yielding asset. Despite the high-yielding asset exhibiting decreasing returns, low wealth-agents pursuing the defensive strategy end up with a portfolio yielding lower returns. This finding indicates that poor households pay high premiums in the form of foregone returns in order to stabilize incomes – it is thus in line with early empirical findings (Rosenzweig and Binswanger, 1993; Morduch, 1995) in the literature.

While both, asset-rich and -poor households, achieve some consumption smoothing, the asset-poor are less successful in doing so. While the former allow only one-third of the volatility in income to be passed on to consumption, the latter allow more than one-half to be passed on. It is interesting that the asset-poor could achieve more consumption smoothing, yet they deliberately de-stabilize consumption in order to protect the few assets they have. Zimmerman and Carter refer to this as *asset smoothing* – in contrast to *consumption smoothing*. This result, in essence a consequence of the threat to subsistence the poor face and the additional price risk livestock carries, is in contrast to much of the earlier literature on this topic. However, the assumptions imposed concerning the subsistence threat are rather stark. The consumption-productivity link is captured by the specification of a minimum subsistence level below which utility is zero for that period and all periods thereafter. The model's prediction of different regimes is supported by the empirical evidence presented in Carter and Lybbert (2012). However, their results suggest that if any, only a small fraction of households engage in consumption smoothing.

More sophisticated models that account for price effects highlight the importance of grain stocks as a means to smooth consumption (Saha and Stroud 1994; Park 2006). Park (2006), in particular, formulates a model that captures the multiplicity of farmers' grain management options – storage, production, trade, and consumption – in a dynamic specification. His model accounts for both yield and endogenous price risk. Simulating the model he finds that households hold grain storage as a price hedge, not in lieu of credit or other *ex-post*-consumption smoothing mechanisms. In the absence of price risk, households would abstain from storing any grain.

To summarize, while the theoretical literature clearly acknowledges the importance of prices for the viability of households' coping strategies, the empirical literature reflects this only to a limited extent. This paper aims to fill this gap by explicitly studying price effects in section 3.7.

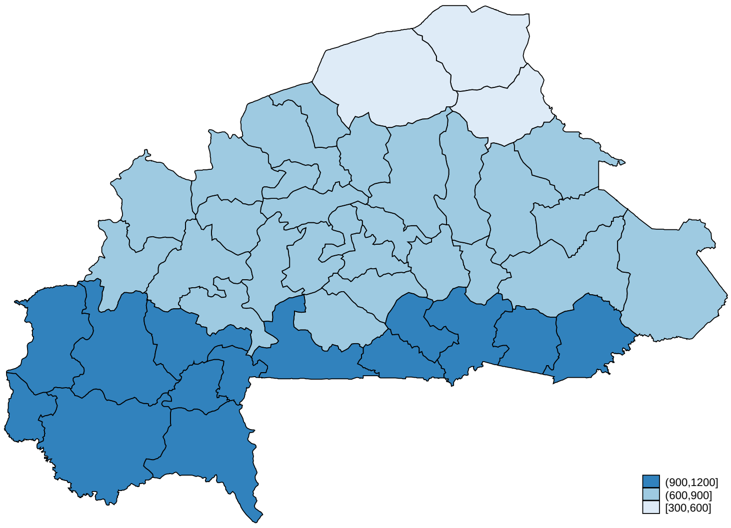
3.2.2 Agricultural production in Burkina Faso

Burkina Faso is a landlocked country located in West Africa. It is among the poorest countries in the world with a PPP-adjusted GDP per capita of about $450 in 2009 (in 2005 dollars - WDI 2013). More than two-thirds of the population lives on less than $2-a-day. As in other Sahelian countries, most of the poor still live in rural areas where livelihoods depend crucially on rain-fed agriculture. While the share of agriculture in total output accounts for about one-third, the sector employs four in five persons in Burkina Faso. The rate of technological change in agricultural production in the WASAT is low (Eicher and Baker 1982).

According to definitions by Sivakumar and Gnoumou (1987), there are three distinct climatic zones in Burkina Faso[82]: a *Southern Sudanian Zone* to the south characterized by rainfall above 1,000 mm annually on average, a rainfall season that lasts for more than six months, and comparatively low temperatures; a *Central North Sudanian Zone* with rainfall between 650 and 1,000 mm that does not exceed six months; and a *Northern or Sahelian Zone* with a short rainy season, considerable variability in rainfall and high temperatures. These three climatic zones roughly coincide with the shaded areas in the map depicted as figure 13 which clearly shows the north-south-gradient in average annual precipitation in millimeters between 2001 and 2012. While onset dates differ somewhat across regions, most of the rain is typically received between June and September.

[82] Some authors distinguish four distinct agro-ecological zones (e.g. Fontès and Guinko 1995).

Figure 13: Average annual precipitation in millimeters, 2001–2012



Source: Authors' calculations based on data from USAID (2013), 2001–2012.

Crops grown for domestic consumption are mostly sorghum, millet, maize, and rice (see Kassam (1979) for an early exposition). Millet is the dominant staple crop in the arid northern provinces on steep slopes and otherwise poor soils, while sorghum is the principal subsistence crop elsewhere (Sivakumar and Gnoumou 1987). The most important cash crop is cotton, despite a sharp decrease in world market prices in the mid-2000s. The initial surge in production originated in reform efforts that date back to the early 1990s. The next ten years saw a more than three-fold increase in production (see Kaminski, Headey, and Bernard 2011). Today cotton accounts for more than half of the countries' export earnings (Amo-Yartey 2008). Production is concentrated in the southwestern regions. Driven by the boom in cotton production on the one hand and recurring droughts in the north on the other, the region has seen more rapid change than the rest of the country with a shift towards cotton and maize production, more rapid population growth due to intra-national migration, as well as higher adoption rates of advanced agricultural techniques such as animal traction and the use of anti-erosion sites (Gray 1999). In the Sahel, in contrast, cash crops include groundnuts and sesame but at a smaller scale (Traore and Owiyo 2013).

Animal husbandry, dominated by goats, sheep, and cattle, is traditionally an important source of incomes in this region and in the east of the country (Sivakumar and Gnoumou 1987). More recent reports, however, point to a decline in the economic importance of livestock in the Sahel in recent years – particularly in response to droughts in 2004 and 2010. For instance, Traore and Owiyo (2013) point out an accelerated degradation of pastures in recent years due to a decrease in rainfall. Consistent with a shift towards more intensive livestock management practices, respondents in their study also report a shift away from purely cattle-based livelihoods towards a combination of crop production and livestock keeping.

3.3 Datasets

For the empirical part of our paper, we are using two different panel datasets which both cover the 2004 drought (namely: *Enquête Permanente Agricole* (EPA) and *Deuxième Programme National de Gestion des Terroirs* (PNGT)) together with precipitation data from the Famine Early Warning Systems Network (FEWS) (USAID 2013). These datasets are separately described below.

3.3.1 EPA surveys

In comparison to the ICRISAT data that were used by most authors from the literature, the EPA panel datasets (years 2004–2007) have the great advantage that they are not as outdated as the ICRISAT data (collected between 1981 and 1985) and that their sample size is much larger (our balanced panel contains 2,364 households annually instead of just 126 households in the still unbalanced ICRISAT panel). In addition, the EPA data cover all 45 provinces of Burkina Faso and can therefore be considered much more representative for rural areas of the country than the ICRISAT data which are restricted to just six villages across three different agro-climatic zones.

Besides these advantages, the EPA household data share many of the desirable features of the ICRISAT data. Most importantly, they rely on interviews conducted by local enumerators coming from the same area who are typically farmers themselves and are hence very familiar with the local conditions for agriculture. Furthermore, this proximity enables them to visit the surveyed households not just once, but at different points in time (mostly during the growing and harvest season). Lastly, given its major importance for the Burkinabe Ministry of Agriculture as a tool to collect information on past and expected future harvests, extraordinary efforts are made to capture each household's agricultural production as precisely as possible. For example, each local enumerator is equipped with an isosceles triangle which is used at the first visit during the growing season to randomly mark on each plot an area of exactly 25m^2 with wood pegs (randomness is assured by following an exhaustive predefined process). Shortly before the plot is ready to be harvested, the household head then contacts the enumerator and agrees on a date when the household will be re-visited. This allows the enumerator to be present when the marked area is harvested, threshed, weighed and the measured output ultimately extrapolated to the entire plot area.[83]

[83] This procedure apparently worked quite well since, according to the data, an enumerator was present at the time of harvest in almost 60 percent of the cases.

The above-described procedure together with very strict protocols also for other questionnaire modules lets us be confident that – in terms of data quality – the EPA data are of comparably high quality as the commonly used ICRISAT data.

3.3.2 PNGT surveys

In addition to the above-described EPA datasets, we are using two waves of the PNGT panel surveys for our analysis which were collected in May/June 2004 and 2005, respectively, and thus likewise cover the 2004 drought.[84] These surveys are administered by the University of Ouagadougou in collaboration with the Burkinabe Ministry of Agriculture and aim to quantify improvements in the livelihoods of households in rural Burkina Faso. The surveys cover a total of 60 villages in all 45 provinces and aim to be representative for rural Burkina Faso given that each village was drawn with a probability proportional to its population (Wouterse 2011).

The motivation for additionally using the PNGT panel lies in the fact that the EPA datasets indeed provide reliable information on agricultural production, livestock holdings/transactions as well as grain stock holdings, but lack an explicit consumption module. The PNGT surveys provide remedy to this shortcoming since they were collected in each year's lean season and contain a very detailed expenditure module as well as a module asking for the food quantities consumed during the last seven days. This feature enables us to grasp the extent to which harvest shortfalls translated into actual reductions of food consumption without relying on flow accounting methods such as Kazianga and Udry (2006).

3.3.3 Descriptives

Table 8 reports descriptive statistics for some of the key variables in our analysis. As further detailed in section 3.4, our data cover a major drought in the northern part of Burkina Faso in the year 2004 which caused the grain output to be considerably lower. Households in the EPA data comprise on average around eleven members while households are slightly smaller in the case of the PNGT data. Also, we observe that the latter have younger household heads and fewer

[84] In fact, we also have access to a third PNGT wave that was collected in November 2006. However, after careful consideration, we decided not to use this third PNGT wave for our analysis given that the shift in the survey timing would complicate comparisons over time. Even more importantly, this shift also leads to a break in the panel structure of our data since we would then only have harvest data for agricultural seasons 2003/04, 2004/05, and 2006/07, but not for agricultural season 2005/06.

livestock holdings. The figures also seem to indicate that they have lower grain output despite cultivating more land.[85]

The drought year of 2004 is apparent in the data via a reduction in aggregate grain output and crop profit that is observed in both datasets. Grain stocks few weeks before harvesting, which are only available from the EPA datasets, are much lower in 2005 than in 2004. However, averages reported in table 8 disguise considerable spatial variation. Therefore, section 3.4 scrutinizes the effects of the 2004 events in more detail with a particular focus on livestock related variables.

Table 8: Descriptive statistics

	EPA				PNGT		
	2004	2005	2006	2007	2003	2004	2005
Household size	10.95	10.97	10.92	10.95	--	9.21	10.10
	(6.74)	(6.85)	(6.94)	(6.83)		(5.79)	(6.30)
Age of HH head	50.99	51.27	51.53	51.77	--	48.26	49.21
	(14.90)	(14.85)	(14.47)	(14.60)		(15.50)	(15.32)
Mean age of HH members	22.37	22.70	23.02	23.14	--	22.31	22.31
	(7.96)	(8.52)	(8.61)	(8.56)		(8.93)	(8.71)
Cultivated area (ha)	4.03	4.15	4.04	4.09	--	5.31	5.09
	(3.37)	(3.58)	(3.47)	(3.48)		(5.08)	(5.41)
Agg. grain output (kg)	2,233.43	2,955.98	2,861.26	2,566.60	1,716.10	1,206.49	--
	(2,388.95)	(2,968.61)	(2,870.08)	(2,914.91)	(1,825.60)	(1,345.96)	
Crop profit (1,000 CFA)	486.63	572.81	567.36	463.56	322.43	273.43	--
	(547.04)	(607.03)	(575.17)	(551.02)	(430.60)	(340.09)	
Agg. grain stock (kg)	324.61	116.04	283.23	301.96	--	--	--
	(753.25)	(408.43)	(625.40)	(690.89)			
Herd size (cattle equiv.)	8.13	7.67	7.90	7.53	--	4.67	4.79
	(20.35)	(18.35)	(22.55)	(18.78)		(11.73)	(12.36)
Observations	2,364	2,364	2,364	2,364	1,492	1,492	1,492

Notes: Standard deviations reported in parentheses. To calculate tropical livestock units (TLUs) we follow Jahnke (1982): cattle enters with a weight of unity while sheep and goats enter with a weight of one-seventh. TLUs are thus `cattle equivalents'.

3.3.4 Prices

A typical problem that we encounter with the otherwise excellent EPA data is the elicitation of crop prices. This is because the data neither come with a village level-survey in which local market prices were collected separately by enumerators as in the case of the PNGT data, nor do they include an actual consumption aggregate. Hence, the researcher is usually left with prices inferred from unit values calculated from households' reports on sales of its agricultural output.

Such sales, however, are rare in an environment characterized by subsistence farming and low incomes. In general, households will sell their own-produced grains only when prices are particularly good. For instance, Barrett and Dorosh (1996) report that of their sample of rice-producing farm households in Madagascar only five percent of households accounted for about half of rice sales while about 60 percent purchased rice. Similarly, Budd (1999) shows that few of

[85] A possible explanation for this is recall bias: output is directly measured in the case of the EPA data, often in the presence of enumerators, whereas the PNGT data rely on recalls elicited during the following lean season, i.e., several months after harvesting.

the farm households in Côte d'Ivoire that he studies were fully self-sufficient and very few were net sellers. This finding is usually attributed to high transaction costs in environments with poor infrastructure (e.g. Renkow, Hallstronm, and d. Karanja 2004; Park 2006).

The same is true in our data: households are rarely net sellers of crops. When asked about the proceeds from the 2003/04 bumper crop in mid-2004, in as many as eight out of 45 provinces less than ten households report having sold millet. This share increases to 21 out of 45 provinces with regard to ag. season 2004/2005. The problem is even more pronounced in the case of non-grain crops such as Wandzou for which we hardly ever observe more than ten transactions from which unit prices could be calculated.

Another potential problem is intra-seasonal price variation. Respondents were asked about sales of output between the last harvest and the time of the interview, a period of almost ten months in the case of the EPA surveys. Intra-seasonal prices in African agriculture are known to fluctuate substantially within localities, a phenomenon that has received some attention recently (Stephens and Barrett 2011; Burke 2014). We would thus expect average unit prices based on reported sales to exhibit high variability within province-years.

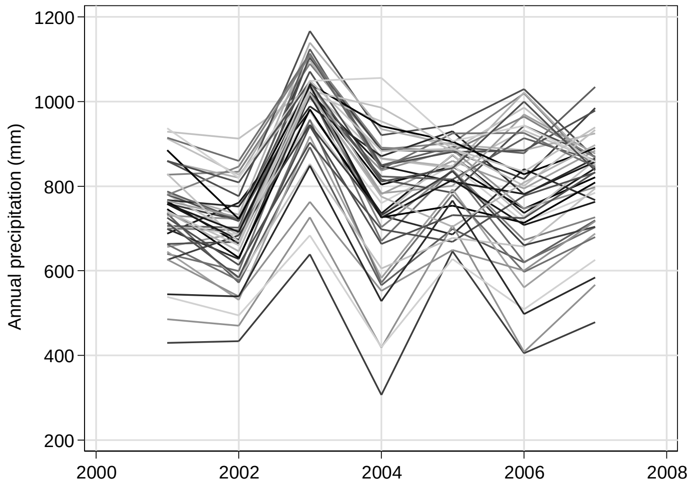
We therefore rely on an alternative that takes advantage of the fact that the PNGT data provide us with village-level prices from all provinces at three different points in time between spring 2004 and fall 2006 (see also footnote 84). These data are used to calculate province-level prices and are then supplemented with monthly crop price data for Ouagadougou from the *Statistical Yearbooks* of the *Institut National de la Statistique et de la Démographie* (INSD 2012). We then impute province-level prices based on regression models (details are reported in appendix C1).

These prices, together with average expenditure shares estimated based on data from the PNGT surveys' consumption modules, are then used to compute a province-level consumer price index (CPI) as follows: first, we calculate the average annual quantities consumed of the major food items for which we have prices in the PNGT village-level surveys over all households and years. Second, these quantities are valued using the current province-level market prices giving us the monetary value of the food basket. On average, food expenditure accounts for roughly two-thirds of total consumption expenditure of the households in the PNGT sample. For non-food expenditures, accounting for the other third of the basket of goods, we assume a moderate inflation rate of three percent annually. The resulting CPI is normalized to be unity on average across all households and time periods.

3.3.5 Precipitation data

The precipitation data used in this paper come from USAID (2013) and are estimated based on a combination of actual station-level rainfall data and satellite-measured cloud top temperatures. For our analysis, we downloaded province-level precipitation data for ten-day intervals for the years 2001 until 2012 (i.e. 36 data points per year and province). Based on these raw data, we calculate the amount of rainfall in millimeters for each province-year separately.

Figure 14: Annual precipitation in 45 provinces, 2001–2007



Source: Authors' calculations based on data from USAID (2013), 2001-2007

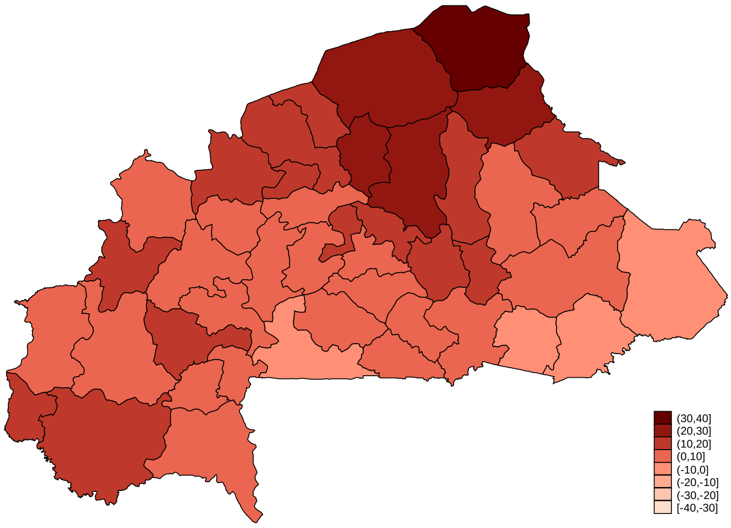
The resulting panel is depicted as a time series plot for all of Burkina's 45 provinces in figure 14. It is clear from this figure that 2003 was a particularly good year in almost all provinces whereas 2004 saw less rainfall.

3.4 The impact of the 2004 drought

Causes In terms of agricultural production, 2004 was a particularly bad year for farmers in the northern provinces of Burkina Faso. The rainy season started later than usual, precipitation was irregular and overall rainfall levels were considerably below the long-term mean (FAO, 2005).[86] This shortfall in rain is depicted in figure 15, where we report the proportional shortfall in 2004 relative to the long-term mean calculated for 2001–2012. On average, provinces experienced about ten percent less rain in 2004. Provinces most severely hit during that year were Namentenga, Oudalan, Sanmatenga, Séno, and Soum. In the northernmost province, Oudalan, generally one of the driest provinces within Burkina Faso, rainfall levels were about 30 percent below the long-term mean.

[86] In addition, there were reports of desert locust swarms from North Africa invading many West African Sahel countries including Burkina Faso (IFRC 2005). This phenomenon also affected primarily northern provinces and is likely to have further aggravated the loss of output and grain stocks in 2004.

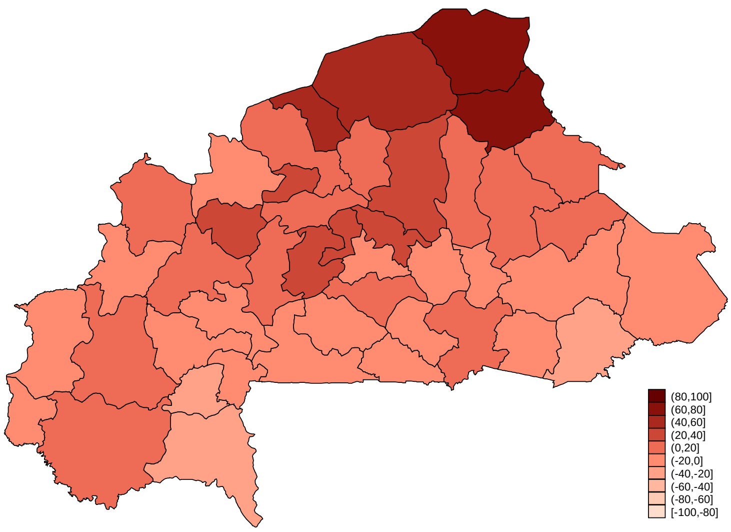
Figure 15: 2004 shortfall in precipitation relative to long-term mean (in %)



Source: Authors' calculations based on data from USAID (2013), 2001–2012

Crop Output The consequences of these events are reflected in figure 16 which depicts the shortfall in crop output per hectare relative to the 2004–2007 average. In line with the above explanations, the output shortfall was largest in the three provinces Oudalan, Séno and Soum which suffered from an average shortfall in excess of three-fourths. Also beyond these three provinces, the rainfall map in figure 15 and the output per hectare map in figure 16 match quite well and suggest a relationship between these two indicators. At the national-level, we observe an average shortfall in output per hectare of slightly more than 25 percent.[87]

Figure 16: 2004 shortfall in crop output relative to 2004–2007 average (in %)



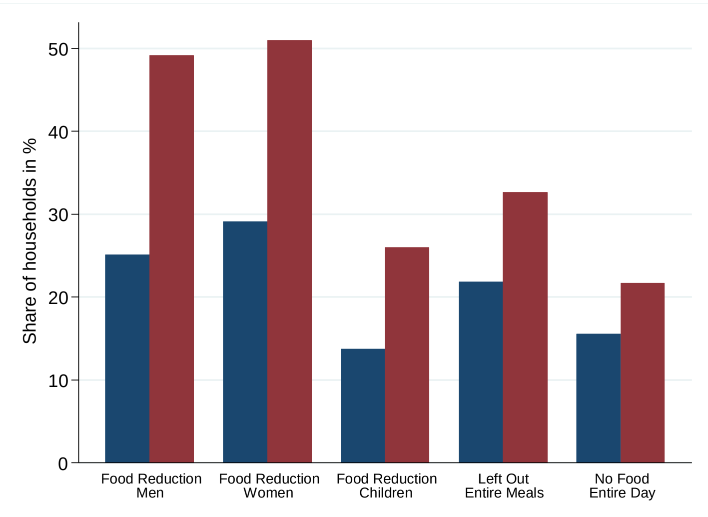
Source: Authors' calculations based on EPA data, 2004–2007

Food Consumption Data from the PNGT surveys also allow us to examine how Burkinabe households reacted to the events of 2004 in terms of consumption. Figure 17 depicts the share of households reporting reduced food in-take during the last seven days (separately for men, women

[87] All figures are unweighted averages across provinces.

and children) as well as the share that left out entire meals or did not consume any food for an entire day in this time period. Three issues are particularly noteworthy. First, a considerable share of households in rural Burkina Faso is structurally poor given that, even following a good year in terms of rainfall and output such as 2003, between 25 and 30 percent of households report reduced food in-take for at least some household members. More than 15 percent of households even report going without food for at least one day during the last week. Second, it seems that households try to protect their children from food cuts to the extent possible given that the share of men/women experiencing reduced food consumption is in both years considerably higher than for children. Third, for all five indicators we see a clear upward shift between 2004 and 2005. Most notably, the share of households reporting reduced food in-take for men/women increases considerably to around 50 percent. This trend does not spare children since in the year 2005 approximately 26 percent of households report food cuts for children (compared to 14 percent in 2004). Analogously, the share of households abstaining from food consumption for an entire day also increases to approximately 22 percent.

Figure 17: Reported cuts in food consumption during the 2004 lean season (blue bars) and the 2005 lean season (red bars)



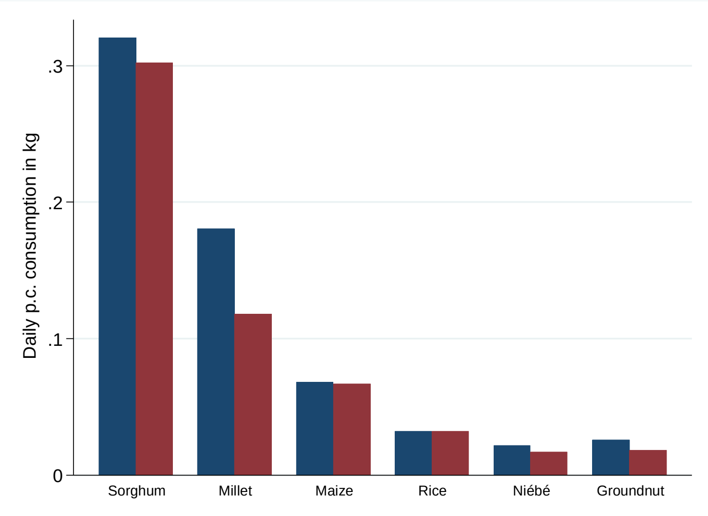
Source: Authors' calculations based on PNGT data, 2004–2005

While these time trends are indicative, it could be argued that they rely on rather subjective, categorical questions. Therefore, we analyze as a next step the daily food quantities consumed per capita for a total of nine crops.[88] As can be seen in figure 18, there has been a considerable drop in millet consumption between the years 2004 and 2005 (approximately 70g per person and day) and to a smaller extent also for Sorghum, Groundnut and Niébé. Even though these reductions appear small at first sight, they nevertheless correspond to a reduction in food intake of

[88] Namely, the contemplated crops are: Fonio, Groundnut, Maize, Millet, Niébé, Rice, Sesame, Sorghum and Wandzou. In figure 18, only six crops are shown since the average amounts of the other three crops (Fonio, Sesame, and Wandzou) are negligible.

approximately 330kcal from these crops (using calorie conversion factors from FAO (2010)). In this context, it should be noted that all nine crops together account for the median household in our dataset for approximately 70 percent of total food consumption.

Figure 18: Daily per capita consumption (kg) of staple food during the 2004 lean season (blue bars) and the 2005 lean season (red bars)



Source: Authors' calculations based on PNGT data, 2004–2005

Livestock ownership and trading Are the 2004 events also reflected in livestock budgets? Table 9 reports means of variables related to production and trading of livestock for all available years. Livestock holdings are substantial in this setting: about three-fifths of all households report owning cattle and more than four-fifths own small livestock, i.e. sheep or goats. On average, families own more than five heads of cattle and more than 13 heads of small livestock in any year.

Table 9: Livestock balance for cattle and sheep/goats, 2004–2007

	2004	2005	2006	2007
A. Cattle				
% of households owning livestock	0.60	0.59	0.60	0.58
% of households reporting sales	0.22	0.23	0.23	0.22
# of animals owned	6.04	5.76	5.97	5.64
# of animals sold	0.54	0.68	0.54	0.58
# of animals deceased	0.48	0.49	0.40	0.37
# of animals slaughtered	0.03	0.21	0.03	0.02
# of animals purchased	0.34	0.38	0.30	0.31
# of animals born	1.31	1.29	1.17	1.07
B. Sheep/Goats				
% of households owning livestock	0.85	0.82	0.83	0.83
% of households reporting sales	0.55	0.50	0.52	0.46
# of animals owned	14.59	13.40	13.52	13.22
# of animals sold	2.59	2.60	2.22	2.10
# of animals deceased	2.65	2.60	1.72	1.92
# of animals slaughtered	0.84	1.70	0.76	0.69
# of animals purchased	1.26	1.09	0.85	0.84
# of animals born	5.98	5.60	5.13	5.08

Notes: Authors' calculation based on EPA data, 2004-2007

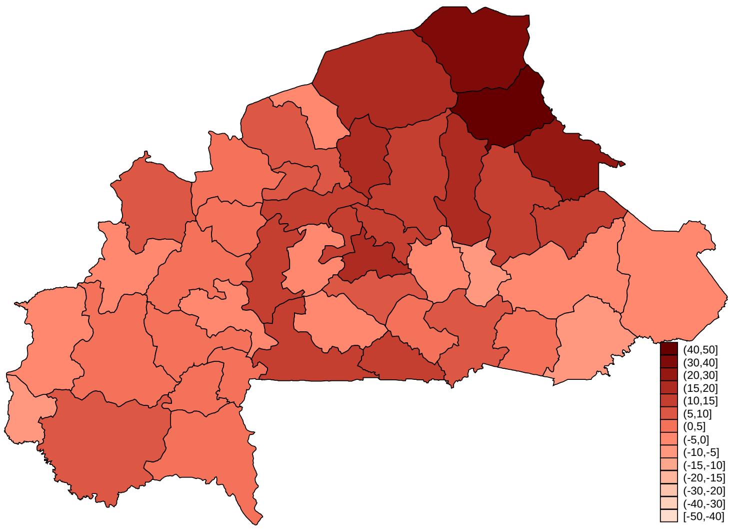
The share of households selling is lower: less than one-fourth of all households sold cattle, while about half report having sold small livestock. While there is virtually no increase in the number of households selling cattle between 2003/2004 and 2004/2005, the average number of cattle sold increases in 2004/2005 from 0.54 to 0.68 animals. No such increase is observed for small livestock although sales were higher in 2004/2005 than in subsequent periods.

While the figures do not indicate that there was an increase in the number of animals that died as a result of drought, the number of animals slaughtered increases substantially in 2004/2005, albeit from a very low level. This is surprising as several previous studies find that households rarely kill animals for own-consumption (see Fafchamps, Udry, and Czukas 1998, and studies cited therein).

These averages disguise important spatial variation in sales. Figure 19 depicts net livestock sales relative to initial holdings (in percent) between harvests in 2004 and 2005. As in table 8, we combine different categories of livestock by considering livestock holdings and net sales in TLUs. In line with our expectations, the proportion of animals sold net of purchases is highest for the most drought-affected provinces in the North of Burkina Faso where households on average sold more than 30 percent of their livestock.

However, this could also be a static effect if households in northern provinces have a higher tendency to engage in animal husbandry because of underlying differences in the rural economy. It is thus plausible that the pattern observed in figure 19 is unrelated to changes in rainfall and crop output. We will investigate this issue in more detail in section 3.5.

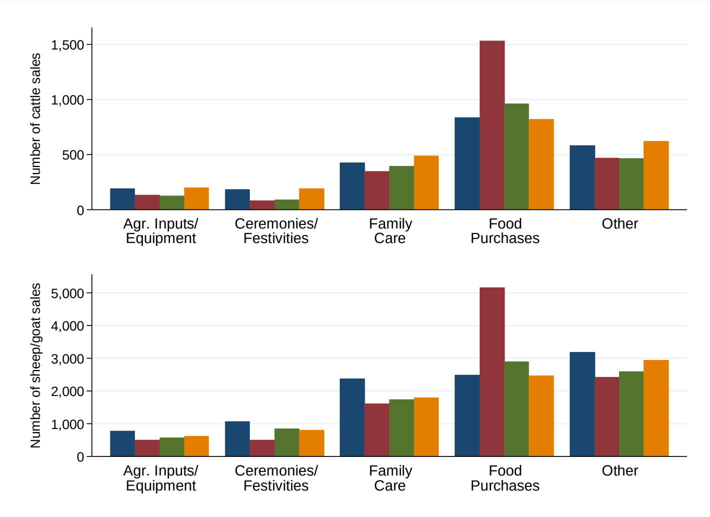
Figure 19: Net sales of livestock relative to initial holdings (in %), 2004–2005



Source: Authors' calculations based on EPA data, 2004–2005

The EPA surveys also collect information on households' motives for livestock sales. The absolute number of sales of cattle as well as sheep and goats by motive is depicted in figure 20. We see that food purchases are the most prominent single motive in all years, followed by family care. Other categories, such as obtaining funds to pay for ceremonies and festivities as well as for agricultural inputs and equipment are less important. The pattern is fairly stable across years with the exception of sales to pay for food which almost double between harvests 2003–2004 and 2004–2005.

Figure 20: Motives for sales of cattle and sheep/goats between harvests of 2003–2004 (blue bars), 2004–2005 (red), 2005–2006 (green), and 2006–2007 (yellow)



Source: Authors' calculations based on EPA data, 2004–2007

Taken together, the figures presented in this section show that livestock sales increased substantially during the agricultural season 2004/2005 and that the dominant motive behind sales was households' need to purchase food. It seems plausible that these extra sales were triggered by adverse rainfall conditions and the resulting shortfall in crop output. The next two sections investigate the relationship between rainfall and livestock sales more formally.

3.5 Rainfall and livestock trading

The above observations are consistent with households resorting to livestock sales in response to adverse weather conditions. To further investigate this conjecture, we first run fixed effects-regressions of the log quantity of livestock sold on log rainfall at the province-level in section 3.5.1. In section 3.5.2, we then investigate the same relationship at the micro-level based on conditional Poisson regression models for the number of animals sold.

Since we control for unobserved, time-invariant variables at the level of provinces and households, respectively, the coefficient on log rainfall should be interpreted as the effect of changes in rainfall conditional on long-run averages. We show in appendix C2 that rainfall levels at particular locations across Burkina Faso do not exhibit any significant trends over time. Moreover, we find no evidence for serial correlation in the location-specific time series. We thus maintain that deviations of rainfall from long-run means are unanticipated.

3.5.1 Rainfall elasticities of livestock sales and purchases

We first run regressions of the form

$$\ln(x_{pt}) = \delta \ln(rainfall_{pt}) + p_p + \tau_t + \varepsilon_{pt} \tag{3.1}$$

where x_{pt} denotes either sales or purchases of cattle or sheep/goats in province *p* during year *t* and ε_{pt} is the usual error term. Since both sales (purchases) and rainfall enter the regression in logs, the coefficient of interest, , should be interpreted as the elasticity of sales (purchases) with respect to rainfall. A negative coefficient in a regression of sales on rainfall is consistent with consumption smoothing, i.e. it is consistent with households selling livestock in order to stabilize consumption.

All regressions include complete sets of province- and year-fixed effects denoted p_p and τ_t , respectively. Province-fixed effects capture time-invariant differences in livestock production across provinces. For instance, it is plausible that some geographical regions provide a relative advantage in producing livestock such that rural households are more likely to engage in animal husbandry. In that case, we would expect higher sales and purchases in every year. Year-fixed effects, on the other hand, capture trends in the supply and demand conditions that affect all provinces to the same degree such as world market prices for meat.

Table 10: Rainfall elasticities of sales and purchases of cattle and sheep/goats, 2004–2007

	Log quantity sold of…		Log quantity purchased of…	
	…cattle	…sheep/goats	…cattle	…sheep/goats
	(1)	(2)	(3)	(4)
Log rainfall	-0.72**	-0.81*	0.08	0.09
	(0.34)	(0.44)	(0.30)	(0.36)
# of obs.	178	180	179	180
R-Squared	0.80	0.58	0.81	0.71

Notes: Robust standard errors clustered at the province-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. All regressions include province- and year-fixed effects. Based on EPA data.

Results for cattle as well as sheep and goats combined are reported in table 10. Elasticities reported in columns (1) and (2) suggest that sales of both categories of animals decrease with better rainfall. The implied elasticities are large and significant at the five and ten percent-levels for cattle and sheep/goats, respectively. This finding is consistent with livestock serving as a buffer stock and differs from those reported by Fafchamps, Udry, and Czukas (1998) in their study of consumption smoothing in six Burkinabe villages during the early 1980s. In particular, at the village-level they find no statistically significant relationship between rainfall and the number of cattle sold and only a weak relationship for sheep and goat. Kazianga and Udry (2006) and Carter and Lybbert (2012) do not investigate this reduced-form relationship but rely on the same data.

If village economies were completely isolated, we would observe a concomitant increase in purchases. In that case, we would see animals being traded between villagers forced to sell in the wake of a bad harvest and others taking advantage of an increase in supply. This could potentially explain the puzzle found in the literature that, on average, there is no relationship between revenues from net sales and transitory income shocks. However, this explanation seems unlikely: in any given year, we find that, on average, the number of animals sold exceeds the number of animals purchased by a factor of two (see table 9). We also estimate absolute rainfall elasticity of purchases. Results are reported in columns (3) and (4) of table 10. These suggest that purchases do not vary significantly with rainfall. Taken together with lower purchases, this implies that increased sales are not absorbed within provinces through concomitant increases in purchases through rural households covered in our sample. A plausible explanation for this is that livestock is sold to butchers in urban localities.

3.5.2 Count data models

Having examined the relationship between rainfall and sales at the province-level, we now turn to the relationship at the level of households. Since sales are nonnegative integers, count data models are appropriate. We opt for the conditional (fixed effects) Poisson estimator (FEP) originally proposed by Hausman, Hall, and Griliches (1984) which has several advantages[89] over alternatives such as the fixed effects-variant of the Negative Binomial estimator.[90]

[89] Inference in standard Poisson models relies on the *Poisson variance assumption* that states that the conditional mean must equal the conditional variance (Wooldridge 2002, pp. 646–647). While there is evidence for overdispersion in our data – the standard deviation of sales of cattle, sheep, and goats is typically about three times the mean – Wooldridge (1999) shows that the only assumption required for consistency and asymptotic normality of the FEP estimator is that the conditional mean be correctly specified. In particular, the distribution of the dependent variable conditional on covariates and the fixed effects is entirely unrestricted; there can be overdispersion (or underdispersion) in the latent variable model.

[90] Allison (2000) and Greene (2005) show that the commonly used fixed effects-variant of the negative binomial model is not a "true" fixed effects-model as it builds the fixed effect into the variance of the random variable, not the mean.

The mean function is specified as

$$m(\mathbf{x}_{it}, \beta) = c_i e^{x'_{it}\beta} \tag{3.2}$$

where c_i is a multiplicative fixed effect, $\mathbf{x}$, the matrix of covariates, includes a constant and β is the vector of parameters of interest. Note that (3.2), by far the most popular choice for the mean function, has the advantage that parameters are easily interpreted as elasticities if regressors are included in logs (Wooldridge 2002, pp. 647–648). If they are included in levels, multiplying the coefficient by one hundred yields the semi-elasticity.

One drawback of the FEP estimator is that households for which the number of sales in all time periods is zero are not used in the estimation procedure.[91] The subsample to which the analysis applies is thus the set of households for which positive sales are observed at least once. This reduces the number of household-year observations available for estimation, particularly in the case of cattle as only about 44 percent of households actually sold cattle at least once. The share of households selling small livestock at least once, in contrast, is more than four-fifths. There are important differences between selling and non-selling households which we report on in appendix C3. This is an important issue to keep in mind when comparing results from this section to those in section 3.6. Our way of dealing with this is to adjust samples in section 3.6, so that they match samples available for estimation in the present section.

Results are reported in table 11 for both categories of livestock. In addition to log rainfall, the main variable of interest, we also include year-fixed effects in order to control for aggregate shocks to demand and supply conditions. Moreover, we include (but do not report) a set of household demographic variables in order to control for available family labor.

Other motives besides consumption smoothing might play a role in the decision to sell livestock (Moll 2005). In particular, households may make adjustments by selling livestock in order to maintain the optimal herd size. All regressions therefore include the number of animals purchased, born, and deceased over the last year. As a robustness check, models reported in columns (2) and (5) also include the number of animals owned and the log of the area cultivated in the previous period. Note that including these variables further reduces the number of observations available for estimation.

[91] The FEP estimator is based on quasi-conditional maximum likelihood methods. The sum of counts across time is conditioned on in order to remove the unobserved c_is.

Finally, we also include an interaction term between log rainfall and a binary variable that is unity if the household owns more than 15 cattle equivalents on average over all time periods. Results are reported in columns (3) and (6). Zimmerman and Carter (2003) and Carter and Lybbert (2012) argue that consumption smoothing is only pursued by a subset of households with high levels of liquid wealth. In particular, Carter and Lybbert find that for the subgroup of households that own more than 15 cattle equivalents, livestock sales compensate for a large portion of shocks to transitory income. If this was the case, we would observe a negative coefficient on the interaction term that signals a higher elastiticity of sales with respect to rainfall in absolute terms for livestock-rich households.

Table 11: Results from conditional (fixed effects) Poisson models for the number of sales of cattle and sheep/goats, 2004–2007

	Cattle			Sheep/Goats		
	(1)	(2)	(3)	(4)	(5)	(6)
Log rainfall	-0.69**	-0.73***	-0.75**	-0.45**	-0.25	-0.52**
	(0.27)	(0.25)	(0.31)	(0.23)	(0.26)	(0.25)
Log rainfall × +15 cattle equiv.			0.14			0.20
			(0.25)			(0.23)
Log area cultivated in t–1		0.07			-0.04	
		(0.08)			(0.06)	
# of animals owned in t–1		0.00			0.00	
		(0.00)			(0.00)	
# of animals purchased	0.02*	0.02	0.03*	0.01***	0.02**	0.01***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)
# of animals born	0.00	0.00	0.00	0.03***	0.03***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
# of animals deceased	0.01	0.00	0.01	0.00	-0.01*	0.00
	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
# of obs.	4,172	2,808	4,172	7,578	5,251	7,578
# of groups	1,044	937	1,044	1,902	1,759	1,902

Notes: Robust standard errors clustered at the province-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. All regressions include year-fixed effects and further controls: age of the household head and age squared, the gender of the head, and the number of household members in a total of eight gender-age cells (the number of males and females below the age of seven, between seven and 14, between 15 and 64, and 65 and above). Based on EPA data.

Results reported in table 11 indicate that cattle sales are responsive to rainfall with an elasticity of about -0.7 (column (1)). The coefficient is significant at the five percent-level and remains unaltered if we include lagged stocks (column (2)). There is no indication that households with large stocks of animals exhibit a higher elasticity of sales with respect to rainfall: the coefficient on the interaction term in column (3) is positive yet insignificant at conventional levels.

Recall that, on average, households in our data sell about 0.5 heads of cattle each year (see table 9) and that in affected provinces the shortfall in precipitation in 2004 relative to the long-run mean was about 30 percent. An elasticity of -0.7 would thus suggest that households facing such a shortfall would step up sales by about one-tenth of a cow.

The coefficient on log rainfall in the regression of sales of goats and sheep is also negative and significant at the five percent-level yet the elasticity is lower in absolute terms: a ten percent-increase in rainfall is associated with a decrease in sales by about 4.5 percent. Since an average household sells about 2.5 animals each year, a 30 percent-decrease in rainfall would be associated with an increase in sales by one-third of a goat or sheep. Again, we find no evidence for differences in the rainfall elasticity between households differentiated by total livestock holdings. The estimated coefficient turns insignificant and is somewhat closer to zero if we include lagged stocks of sheep and goats, where our estimation sample now includes only 5,251 household-year observations rather than 7,578 as before.[92]

The number of animals purchased, born, and deceased, as well as the number of animals owned in the previous period are included in order to control for herd management considerations. Our results indicate that the number of animals purchased is positively associated with the number of animals sold for both categories of livestock. While all other coefficients are insignificant for cattle, we find that the number of animals born increases the number of sales for small livestock.

Overall, the results in this section indicate that deviations of rainfall from the long-run mean affect cattle sales and, to a lesser extent, sales of small livestock.

3.6 Saving out of transitory income

We now investigate by which means farm households absorb adverse transitory income shocks. We start by motivating the empirical model. The PNGT data allow us to investigate the relationships between transitory income and consumption expenditure directly. Using the EPA data, we then consider saving in the form of grain stocks and livestock.

3.6.1 Empirical framework

The empirical model is

$$s_{it} = \alpha + \beta y_{it}^{p} + \gamma y_{it}^{T} + \delta \sigma_{i}^{y} + v_{it} \qquad (3.3)$$

where s_{it} denotes savings of household *i* in period *t* in the form of some stock (i.e. net purchases of livestock or the accumulation of grain stock), y_{it}^{p} and y_{it}^{T} are the permanent and transitory components of total income y_{it} , respectively, and σ_{i}^{y} is the variance of the household's income.

As noted by Paxson (1992), a savings equation that is linear in permanent income, transitory income, and the variance of income such as (3.3) can be obtained by maximizing a utility function

[92] A regression without these two variables but using only the smaller sample excluding observations in 2004 reveals that this is not due to the inclusion of lagged stocks and area cultivated.

that is strongly inter-temporally separable and has either quadratic or constant absolute-risk-aversion (CARA)-form. A linear specification also has the advantage that the coefficients have an easy interpretation: β and γ denote the propensity to save out of permanent and transitory income, respectively: an increase in e.g. transitory crop profit by one CFA is associated with an increase in savings by γ CFA. While we remain agnostic about the degree of saving out of permanent income, we are interested in obtaining an estimate of γ, the propensity to save in different forms out of transitory income. The challenge is, of course, that both y^p and y^T are unobserved in practice. However, there are several ways in which γ might still be identified. As is common in the literature (Paxson 1992; Fafchamps, Udry, and Czukas 1998; Kazianga and Udry 2006; Carter and Lybbert 2012), we rely here on unanticipated variation in the level of rainfall in order to isolate the component of rainfall that is orthogonal to permanent income.

First, write $y_{it}^T = y_{it} - y_{it}^p$ such that

$$s_{it} = \alpha + \gamma y_{it} + (\beta - \gamma) y_{it}^P + \delta \sigma_i^y + v_{it} \quad (3.4)$$

De-meaning this equation allows us to purge $\delta \sigma_i^y$. Write

$$\tilde{s}_{it} = \gamma \tilde{y}_{it} + (\beta - \gamma) \tilde{y}_{it}^P + \tilde{v}_{it} \quad (3.5)$$

where the tilde simply denotes de-meaned variables. This is of course equivalent to introducing a set of household-fixed effects. Equation (3.5) relies solely on variation across time for identification.

Note that if permanent income were (close to) constant over time, an assumption that seems defendable in a setting where there is little technological progress (Deaton 1992), we would actually also have purged permanent income from the equation just by the virtue of allowing for household-fixed effects.[93] If, however, permanent income is changing, IV techniques can be applied in order to estimate γ consistently. In practice, instrumenting is often found to safeguard estimates from attenuation bias due to measurement error. We will return to this issue below.

Allowing $(\beta - \gamma)\tilde{y}_{it}^P$ to be absorbed into the error term, γ can be estimated provided a suitable instrument is available that is correlated with changes in transitory income yet uncorrelated to changes in permanent income. Rainfall levels, conditional on household-fixed effects, are both relevant in the first stage and exogenous in the second. First, rainfall has been shown to be an

[93] In his work on consumption smoothing and saving in Côte d'Ivoire, Deaton (1992) assumes that incomes follow a stationary process. He cites very little real economic growth in rural areas in decades prior to his study in justification of that assumption, an argument that probably also applies to Burkina Faso in the mid-2000s.

excellent predictor of farm profits in the WASAT region. For instance, Carter (1997) shows that about half of the variation in crop profit in the ICRISAT data is accounted for by rainfall variability. While weak instruments are known to potentially result in large biases (Bound, Jaeger, and Baker 1995), Stock and Yogo's (2005) results from Monte Carlo Simulations provide guidance as to how strong instruments should be in the first stage.

The key assumption is that rainfall conditional on controls and household-fixed effects has no effect on savings other than through its effect on crop profit. There are two particular circumstances in which this assumption is violated that are tested routinely in the literature (e.g. Paxson 1992; Fafchamps, Udry, and Czukas 1998). First, if there was a common trend in rainfall over time, it would seem likely that permanent income would also be trending into the same direction. Rainfall would thus be correlated with the error term which includes permanent income – see equation (3.5). While this could easily be remedied by considering only rainfall conditional on households-fixed effects *and* year-fixed effects – something that we will do below – we can also test for trends in rainfall data collected at eight rainfall stations across Burkina Faso that stretch back to the early 1970s. Results are reported in appendix C2. Since we find no evidence for linear trends in these data, we conclude that including a common time trend is not necessarily warranted. This result is in line with Fafchamps, Udry, and Czukas (1998) who find no evidence for a trend over long stretches of their rainfall data.

Second, if rainfall were serially correlated, current deviations from long-term means would contain information on deviations in the future. If the AR(1)-parameter was positive and households were aware of this, they would reason that the likelihood of a bad rainfall-year increases following a bad year. This could lead them to hold on to buffer stocks. In fact, Deaton (1990) shows that serial correlation in the income-generating process will decrease the viability and desirability of precautionary savings. Also in appendix C2, we show that there is no evidence for serial correlation in rainfall.

Our empirical strategy shares key ideas with approaches found in other studies in the literature but there are also some important differences. Fafchamps, Udry, and Czukas (1998), Kazianga and Udry (2006), and Carter and Lybbert (2012) rely on an empirical strategy originally advanced by Paxson (1992) that consists of two steps. First, a regression model for crop profit is specified. This regression typically includes household and farm characteristics, as well as rainfall and interactions of rainfall with farm characteristics on the right hand-side. In addition, this regression typically includes household-fixed effects and, in some cases, village-year-fixed effects (e.g. Carter and Lybbert 2012). Second, crop profit is decomposed into its permanent, transitory, and unexplained component based on the resulting estimates: household-fixed effects and household- and farm-characteristics multiplied with the respective estimates account for permanent income, while transitory income is determined by rainfall and its interactions and, if included, village-year-fixed effects.[94] Finally, the residuals are taken to be unexplained income. Predicted income components are then used on the right hand-side of a regression of saving together with household-fixed effects and a set of controls. The functional form is similar to the one we start with in equation (3.3) in that it relates savings to permanent and transitory income in levels. The difference is that income variability does not appear on the right hand-side and that, instead, unexplained income is also included.

The first step in this strategy amounts to estimating a first stage-equation in an IV-framework manually. Our approach is very similar in terms of the main idea, the reliance on rainfall as an instrument for income in order to identify the effect of transitory income changes. In particular, the assumption that rainfall conditional on household-fixed effects is both unrelated to permanent income and the error term in the second stage is crucial in both frameworks.

In our view there are, however, three advantages of our framework. First, there is no need for us to adjust standard errors in the second stage. Carter and Lybbert (2012), for instance, bootstrap the two steps outlined above in order to account for the fact that the regressors in the second stage depend on estimated quantities. Second, it is unclear how to interpret coefficients on unexplained income. Finally, we can directly conduct tests of over-identifying restrictions provided that more than one instrument is available for transitory income. We return to this in section 3.7.

3.6.2 Consumption

We first investigate whether households adjust consumption in response to shocks to transitory income. Table 12 reports results from regressing consumption expenditure on crop profit, where both variables are in real terms and the latter is instrumented using rainfall levels. All models reported in this section include a full set of household-fixed effects and additional controls including the age of the household head, her age squared, her gender, and the number of family members in a total of eight gender-age cells as in section 3.5. Standard errors are clustered at the level of villages and reported in parentheses.

[94] While Carter and Lybbert (2012) treat the village-year-fixed effect as part of transitory income, Kazianga and Udry (2006) maintain that it would be a mistake to do so as some of it may actually relate to permanent income changes. They do not consider village-year-fixed effects but include the main effect of village-level rainfall in their regression equation.

Columns (1) and (2) of table 12 report results from simple OLS-estimation without and with a year-2005-dummy, respectively. Since only two years of data are available from the PNGT dataset, this is equivalent to running the regression in first-differences.

Table 12: Estimates of the effect of transitory crop profit on consumption expenditure (both 1,000 CFA)

	OLS		IV		Reduced form	
	(1)	(2)	(3)	(4)	(5)	(6)
Crop profit (1,000 CFA)	0.09**	0.09**	0.78**	0.84		
	(0.04)	(0.04)	(0.34)	(0.64)		
Precipitation (mm)					0.13**	-0.18
					(0.05)	(0.13)
Year 2005		-37.43***		2.86		-83.95**
		(13.06)		(39.86)		(34.51)
Cragg-Donald F statistic (weak identification test)						
F-statistic			11.91	1.93		
# of obs.	2,946	2,946	2,922	2,922	2,972	2,972
# of groups	1,485	1,485	1,461	1,461	1,486	1,486

Notes: Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Consumption expenditure and crop profit measured in 1,000 CFA. All regressions include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of household members in a total of eight gender-age cells. Based on PNGT data.

The estimates of the effect of transitory crop profit in columns (1) and (2) both suggest that for each increase in transitory per capita crop profit by 1,000 CFA, consumption per capita increases by about 100 CFA. While these coefficients are significantly different from zero, they are much lower than comparable estimates in the literature. Kazianga and Udry (2006), for instance, report estimates in the range of 0.50–0.75.

IV estimates based on 2SLS are presented in columns (3) and (4). Estimates are computed using Schaffer's *xtivreg28*-command in Stata (Schaffer 2012). We also report Cragg-Donald-*F*-statistics (Cragg and Donald 1993) which can be compared to critical values provided by Stock and Yogo (2005). Our instrument passes the weak identification-test only in the specification that does not include a year-2005-effect.[95]

These estimates are greater than OLS estimates by an order of magnitude. The point estimate in column (3) is at the upper end of the range reported by Kazianga and Udry (2006). It suggests that more than three-fourths of transitory income is transmitted to consumption. However, since we only have two consecutive years of data, standard errors on these coefficients are comparatively large. Based on OLS estimates, one could get the impression that households achieve a high degree of consumption smoothing. As mentioned above, we believe that the difference is due to measurement error in the main explanatory variable, crop profit, a problem that is often compounded when identification relies solely on within unit-variation. Similar discrepancies between OLS and 2SLS estimates with income as the main explanatory variable in a

[95] The critical value for an IV bias relative to the bias in OLS of at most ten percent is 7.03 in this case.

fixed effects-specification have been encountered recently by Bengtson (2010). The problem has also been discussed in the literature on demand for calories (see Deaton 1997).

At the same time, the standard errors on these coefficients are also substantially larger. In fact, while the estimate reported in column (4) is of a similar magnitude, we cannot reject that the coefficient is zero. The finding is not surprising considering the pattern of rainfall during harvests prior to the PNGT surveys (figure 14). Rainfall varies only at the province-level and over time. Considering only rainfall in 2003 and 2004, i.e. rainfall that drives crop profit reported by PNGT households during the lean seasons of 2004 and 2005, slightly more than half of the variation in rainfall is accounted for by province-fixed effects. However, if we also include year-fixed effects, roughly 95 percent of the total in rainfall is captured. Thus, our instrument lacks predictive power when both sets of fixed effects are included. It is important to note that this is not so much of a problem when we analyze EPA data as year-on-year changes in rainfall are much less uniform during later years. Province- and year-fixed effects explain only about 80 percent of the variation in rainfall if we consider the years 2004, 2005, and 2006. We also report results from estimating the reduced forms without and with the year-2005-effect in columns (5) and (6), respectively. Consistent with collinearity between rainfall and the year-fixed effect, the positive and statistically significant effect of our instrument on consumption expenditure vanishes if we include a year-2005-effect.

Despite these shortcomings of the PNGT data, both, the descriptive evidence presented in section 3.4 and our regression results here, suggest that households reacted to a drop in rainfall levels by cutting consumption. In particular, the coefficient in column (3) implies a very sizeable effect of transitory crop profit on consumption expenditure. Albeit insignificant for the reason stated above, the coefficient in column (4) is of similar magnitude.

3.6.3 Grain stocks

Next, we investigate the importance of savings in the form of grain stocks in *ex-post*-consumption smoothing. This is done by regressing subsequent changes in grain stocks (i.e. forward first-differences), valued in real CFA, on crop profit and household-fixed effects and instrumenting crop profit again with rainfall levels. Hence, of the four years of data from 2004 to 2007 in the EPA surveys, the last contributes only one observation on grain stock levels required to construct the first-differenced dependent variable associated with crop profit in 2006. Results are reported in table 13. Again, all regression include additional control variables (not reported) that capture households' demographic make-up. In this case, we also include year-fixed effects in all regressions.

Before considering results from OLS and IV estimations in columns (1) and (2), respectively, note that in contrast to our findings for consumption, the reduced form-estimate indicates that rainfall predicts changes in grain stocks (columns (3)). The coefficient is positive and significantly different from zero at the one percent-level despite our inclusion of year-fixed effects. Since these results are based on EPA data, more time periods are available and the number of households observed in each year is greater. As a result, the Cragg-Donald *F*-statistic reported in column (2) of table 13 indicates that the partial correlation between crop profit and our instrument is sufficiently high (Cragg and Donald 1993).[96]

The result from OLS is reported in column (1) and from IV in column (2). Again, the difference is large: while both coefficients are significant at least at the five percent-level, the IV-estimate is larger by an order of magnitude. As noted above, this is likely due to attenuation bias that is a result of measurement error in the independent variable. The IV-estimate suggests that grain storage plays an important role in *ex-post*-consumption smoothing: households absorb approximately one-fourth of shocks to transitory crop profit by adjusting grain stocks. This is in line with findings reported in Kazianga and Udry (2006) for Burkina Faso during the early 1980s and Udry (1995) for northern Nigeria.

Table 13: Estimates of the effect of transitory crop profit on subsequent changes in grain stocks (both 1,000 CFA)

	OLS	IV	Red.
	(1)	(2)	(3)
Precipitation (mm)			0.08***
			(0.03)
Crop profit (1,000 CFA)	0.02**	0.26**	
	(0.01)	(0.12)	
Year 2005	38.66***	18.10	36.22***
	(3.38)	(11.57)	(4.11)
Year 2006	28.02***	8.70	28.36***
	(3.47)	(10.18)	(3.27)
Cragg-Donald F statistic (weak identification test)			
F-statistic		20.62	
# of obs.	7,071	7,071	7,092
# of groups	2,357	2,357	2,364

Notes: Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Changes in grain stock and crop profit measured in 1,000 CFA. All regressions include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of household members in a total of eight gender-age cells. Based on EPA data.

[96] The test statistic exceeds the critical value, 16.38, reported by Stock and Yogo (2005) that corresponds to a bias in the IV estimate relative to the OLS estimate of ten percent.

3.6.4 Livestock

We now turn to savings in the form of livestock by regressing net purchases of livestock on crop profit. The empirical set-up is the same as in the sections 3.6.2 and 3.6.3. The first three columns of table 14 report results from specifications that mirror those in table 13. The coefficient in the OLS regression reported in column (1) is statistically significant yet close to zero. Again, measurement error is suspected. The IV estimate in column (2) is larger by a factor of about ten yet insignificant at conventional levels of significance. It suggests that 20 percent of transitory crop profit is saved in the form of livestock. Finally, the reduced form coefficient is significant only at the ten percent-level, suggesting a weak partial correlation between rainfall and net purchases of livestock. Taken together, there is little evidence of significant savings out of transitory crop profit in the form of livestock.

These findings are despite the fact that most households' holdings of livestock would have allowed them to completely absorb the income shock caused by adverse weather conditions. If we define the shock as the negative deviation in crop profit from its four-year-mean between 2004 and 2007 and compare this for 2004 to livestock holdings at the end of the lean season in 2005, we find that in each region more than half of the households disposed of enough livestock to compensate for the entire shortfall. In seven out of the 13 regions (including the Sahel) more than 80 percent of the households in our sample had sufficient means in the form of livestock.

Our findings here are in line with the literature as discussed in section 3.2.1. In particular, Fafchamps, Udry, and Czukas (1998) find that at most 30 percent and probably closer to 15 percent of income shortfalls are compensated via livestock sales. The latter is close to the point estimate reported in column (2). While we cannot reject the hypothesis that the coefficient on crop profit in column (2) is equal to 30 percent, it is also insignificantly different from zero.

Table 14: Estimates of the effect of transitory crop profit on subsequent net purchases of livestock (both 1,000 CFA)

	OLS	IV	red. form	IV with interactions			Owners	Sellers	Sellers (only cattle)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Precipitation (mm)			0.06*						
			(0.03)						
Crop profit (1,000 CFA)	0.02***	0.19		0.18	-0.00	0.29	0.18	0.21	0.42
	(0.01)	(0.12)		(0.14)	(0.00)	(0.71)	(0.12)	(0.13)	(0.30)
Crop profit × +15 cattle equiv.				0.02					
				(0.20)					
Crop profit × +25 cattle equiv.					0.00				
					(0.00)				
Crop profit × traction animal						0.73			
						(2.98)			
Year 2005	-7.17	-21.33**	-7.74*	-20.97*	0.04	-69.84	-22.14**	-27.31**	-66.52
	(4.88)	(10.22)	(4.57)	(10.84)	(0.16)	(218.04)	(10.60)	(12.67)	(41.75)
Year 2006	-12.10**	-25.24**	-10.99**	-24.81**	0.16	-63.93	-26.14**	-32.91**	-64.27**
	(5.20)	(10.94)	(5.09)	(11.31)	(0.17)	(179.67)	(11.19)	(13.36)	(29.33)
Cragg-Donald F statistic (weak identification test)									
F-statistic		20.00		6.10	3.97	0.21	19.85	19.37	6.26
# of obs.	7,027	7,025	7,048	7,025	9,428	7,025	6,650	5,561	2,783
# of groups	2,357	2,355	2,364	2,355	2,357	2,355	2,230	1,865	935

Notes: Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Net purchases of livestock and crop profit measured in 1,000 CFA. All regressions include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of household members in a total of eight gender-age cells. Based on EPA data.

We also test whether poor and rich households differ in their propensity to save transitory income in the form of livestock by interacting crop profit with different binary indicators of livestock holdings in 2004. Our choice of indicators is motivated by recent contributions to the literature. Based on Hansen's threshold estimator (Hansen 2000), Carter and Lybbert (2012) find that livestock-rich households during the drought that Burkina Faso experienced in the early 1980s pursue consumption smoothing by stepping up net sales of livestock. The estimates of the threshold they report occurs at roughly 15 and 25 cattle equivalents, depending on whether household-fixed effects are included. We also interact crop profit with an indicator of whether the household uses animal traction in agricultural production.[97]

Results reported in columns (4)–(6) suggest that there are no significant differences between farmers differentiated by livestock holdings and animal traction. The coefficients on interaction terms are insignificant and the hypothesis that both the coefficient on crop profit and the one on the interaction term are jointly zero cannot be rejected at conventional levels of significance in all three specifications. We thus cannot reject the null of no heterogeneity along these dimensions. Note, however, that in this case we instrument with rainfall and its interactions with the indicator of livestock holdings. We thus have two instruments per regression which, in the case of animal traction, seem weak based on the Cragg-Donald *F*-statistic.[98]

The findings from savings regressions differ substantially from those obtained considering only the number of sales in section 3.5.2. As noted above, however, one concern is comparability: since households that are never observed selling livestock do not contribute to the conditional log likelihood in the case of the FEP estimator, results in that section were based on subsamples that are potentially selective. We therefore also investigate savings behavior for the subset of households that owned either cattle, sheep or goats after 2004 (column (7)); those that report positive sales in any of these categories between 2005 and 2007 (column (8)); and those that report postive sales of cattle over this period (column (9)). The last subsample corresponds closely to the subsample used in column (2) of table 11. While all three estimates of the propensity to save in livestock are positive and have the expected sign, they are insignificant at conventional levels.

[97] Most household surveys that cover rural Burkinabe households, including the ones used in this study and the ICRISAT data used by Fafchamps, Udry, and Czukas (1998) and many others, are stratified by whether or not households use animal traction in agricultural production. Kazianga and Udry (2006) explain that this reflects the common belief that there are systematic differences between households with and without animal traction. Acquiring animals for traction possibly requires the disbursement of large amounts of cash or access to credit such that only well-off farmers would have access to that technology. It thus seems reasonable to assume a different response of households to income shocks differentiated by levels of technology.

[98] The critical values in this case are 7.03 and 4.58 for a ten and a 15 percent-relative bias, respectively (Stock and Yogo 2005).

Taken together, the above regressions show that cuts to consumption and adjustments to grain stock go a long way in explaining how households absorb transitory crop profit. For instance, if we would combine our estimates in columns (3) and (2) of tables 12 and 13, respectively, we would already be able to account for all of the change in transitory income.

At least some households might have had the opportunity to resort to other sources of income in order to compensate for output loss due to adverse rainfall. Transfers (including in-kind transfers, remittances, and aid), revenue from non-agricultural businesses, wages from off-farm employment, and the use of credit might play a role in households' risk management. Reardon, Matlon, and Delgado (1988), for instance, show that the share of food aid accounted for 60 percent of transfers received by the poorest households in the Sahelian region of Burkina during the 1984 drought. Reardon, Delgado, and Matlon (1992) argue that non-farm activities of households in the same data were an important means of *ex-ante* income diversification accounting for 30–40 percent of total income. A more recent study by Lay, Narloch, and Mahmoud (2009) that investigates patterns of income diversification in Burkina Faso between 1994 and 2003 concludes that the extent of income diversification stagnated. This issue is further investigated in appendix C4. We find no evidence for a significant negative relationship between crop profit and alternative forms of income.

3.7 Rainfall, prices, and quantities

3.7.1 Evidence from province-level price regressions

In essence, our results above replicate the puzzle reported in the literature, albeit in a more pronounced way: in section 3.5, we have shown that there was indeed a rainfall-induced increase in livestock sales with no off-setting increase in purchases and that, if directly asked about the reason for sales, households cite the need to finance food purchases (section 3.4). This finding differs from what Fafchamps, Udry, and Czukas (1998) find for aggregate sales at the village-level. At the same time, we find no evidence for consumption smoothing via livestock sales in the preceding section.

One possible explanation for this apparent puzzle relates to price adjustments in the wake of adverse weather shocks. If prices for livestock decline in response to a rainfall-induced increase in market supply, the effect of rainfall on net purchases in monetary terms as investigated in section 3.6.4, will be attenuated. To examine whether such an explanation for the puzzle is plausible, we now investigate how prices for livestock react to changes in rainfall. We do so by regressing log prices for cattle, sheep, and goat on log rainfall. The resulting coefficient can thus be interpreted as the rainfall elasticity of livestock prices.

Our data allow us to include both province- and year-fixed effects in our regressions. The set-up is thus the same as in (5.1) only that *prices* are now on the left hand-side of the equation. The province-fixed effects account for province-specific differences in market structures that affect prices and are potentially correlated with levels of precipitation. Year-fixed effects control for common shifts in demand and supply of livestock.

Livestock prices are unit values calculated from the EPA data and then averaged within each province.[99] The precision of these averages will depend on the number of sales reported. Hence, there is an econometric argument for weighting each province-year observation in the resulting panel dataset in proportion to the number of observations for which unit values could be calculated. However, this would give a higher weight to provinces in which many sales are reported, i.e. in which markets are well-functioning, potentially biasing our results towards a lower price response. Running both weighted and unweighted regressions, we find that the differences between the estimated elasticities are only minor. Therefore, we only report the former.

Table 15: Results from province-level fixed effects-regressions of log nominal and log real prices for livestock on log rainfall, 2004–2007

	Nominal price			Real price		
Log price of…	cattle	sheep	goats	cattle	sheep	goats
	(1)	(2)	(3)	(4)	(5)	(6)
Log rainfall	0.30**	0.15	0.10	0.28**	0.13	0.08
	(0.13)	(0.13)	(0.11)	(0.13)	(0.12)	(0.11)
# of obs.	177	177	177	177	177	177
R-Squared	0.75	0.88	0.77	0.77	0.89	0.83

Notes: Robust standard errors in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. All regressions include year- and province-fixed effects. Based on EPA data.

Results are reported in table 15, where we consider both nominal (columns (1)–(3)) and real prices, i.e. prices divided by our CPI discussed in section 3.3.4 (columns (4)–(6)). The estimates reported are positive and statistically significantly different from zero for cattle but not for other types of livestock. The elasticity of the nominal cattle price is 0.30 percent and is significantly different from zero at the five percent-level. Estimated elasticities are also positive but lower for sheep and goat at 0.15 and 0.10 percent, respectively. In both cases, however, we cannot reject that they are zero at conventional significance levels. Estimates are very similar when real prices are considered (columns (4)–(6)).

[99] Households sampled in the EPA surveys were asked to report on quantities and values of livestock sold within the last twelve months.

These results are in line with Fafchamps and Gavian (1997) who find that livestock prices respond to droughts in Niger, a country neighboring Burkina Faso to the northeast. Several authors have also commented on the potential importance of general equilibrium effects in the context of consumption smoothing more broadly (Fafchamps, Udry, and Czukas 1998; Zimmerman and Carter 2003). For instance, Fafchamps, Udry, and Czukas (1998) point out that in the extreme case in which villages constitute closed markets, net sales of livestock will necessarily total zero and that prices will adjust downward accordingly. However, in section 3.5 we found no evidence for a positive elasticity between rainfall and purchases, suggesting that livestock was sold to economic agents not covered by our sample of rural farmers.

Taken together, the results presented in this section potentially explain the puzzling finding in the literature of no consumption smoothing via sales of livestock. In particular, two effects seem to be at work that to some extent have a tendency to cancel each other out. If during droughts prices for livestock drop as a result of increasing sales, net purchases, measured in real currency units, will tend to show less of a tendency to vary with rainfall.

3.7.2 Rainfall, prices, and exclusion restrictions

While the above results explain the apparent lack of association between rainfall and net purchases, it also potentially threatens the appropriateness of rainfall as an instrument for crop profit in a regression of savings on income as in section 3.6. Such specifications derive from partial-equilibrium models in which prices are exogenous. If, however, rainfall affects prices and, at the same time, local prices are important for households' decision in which form to make provisions for the future, rainfall is potentially correlated to the error term in a specification such as (3.5).

In appendix C5, we therefore test underlying exclusion restrictions in two ways: first, we insert prices for cattle and the CPI directly into the estimation equation and test whether they are individually and/or jointly significant. Second, we generate additional instruments and test exclusion restrictions based on standard Hansen/Sargan-type tests. In both cases we cannot reject that our instruments are rightly excluded from the main equation of interest. Thus, in our case, we are confident that coefficient estimates are consistently estimated.

3.8 Conclusion and policy implications

The present paper re-visits a puzzle stated in the empirical literature on optimal saving in developing countries in the absence of formal insurance mechanisms. While livestock holdings were traditionally hypothesized to constitute the main means of households to smooth consumption in the wake of shocks, empirical work in this area usually finds no evidence for a significant relationship between the *monetary value of net livestock sales* and transitory income. On the other hand, studies with a focus on the *number of sales* often find evidence for a sizeable increase in sales in response to adverse shocks.

The event we study is a severe drought in the northern provinces of Burkina Faso that occurred in 2004 and a subsequent return to normal levels of rainfall. Our empirical investigation is based on two household-level panel datasets that provide ample information on consumption, grain stocks, and livestock holdings and transactions.

Our results can be summarized as follows: rainfall negatively affects sales of livestock with no offsetting effect on purchases at the level of provinces. A similar increase in sales in response to adverse rainfall is observed at the household-level. Reportedly, extra sales were a reaction to an increased need to finance food purchases. However, we find no evidence for precautionary savings in the form of livestock – neither among the asset-poor, nor among the asset-rich – while grain storage plays a significant role in *ex-post*-coping. Nevertheless, changes in transitory income are transmitted to a large extent to consumption expenditure.

We then show that cattle prices at the province-level vary positively with rainfall and our estimates suggest that the elasticity is high. This is consistent with a general equilibrium-effect that adversely affects revenues from livestock sales in times of harvest failure, rendering precautionary saving in the form of livestock a costly strategy to smooth consumption. Households thus seem to manage a difficult trade-off between selling more livestock at low prices and destabilizing consumption and safeguarding assets that may fetch higher prices in the future. Consequently, asset-smoothing may be considered the outcome of poor prices to be had in times of crises.

In terms of policy implications, our findings underline the lack of market integration in rural Burkina Faso witnessed by massive price changes and inter-regional discrepancies over the course of the 2004 drought. These imply that savings in forms other than grain stocks are subject to major price risks. An increased focus on integrating livestock markets (e.g. by investing in road infrastructure) would potentially mitigate welfare losses incurred by farm households during episodes of economic distress. Ultimately, of course, appropriate insurance mechanisms should be put in place (e.g. rainfall insurance) that would allow households to stabilize incomes *ex-ante*.

Appendix to Chapter 3

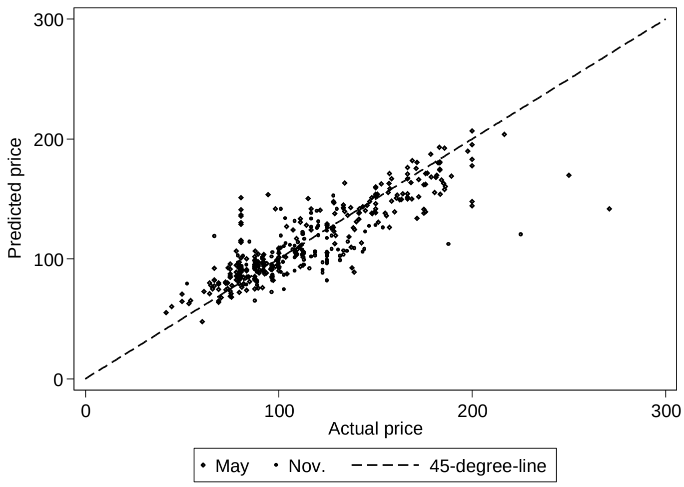
Appendix C1: Imputation of prices

We rely upon predicted crop prices from a regression model fitted to PNGT data based on price data from Ouagadougou which is available for each month. Denote the price for crop *c* in province *p* in year *t* and month *j* (May or November) p_{pctj} and the contemporaneous price in Ouagadougou $p_{ctj}^{Ouag.}$. The model can then be written

$$\ln(p_{pctj}) = \phi_p \ln(p_{ctj}^{Ouag.}) + p_p + \gamma_c + \varepsilon_{pctj} \quad (3.6)$$

where ϕ_p is the province-specific elasticity of price with respect to capital city-price, p_p is a province-fixed effect, and γ_c is a crop-fixed effect. We allow the price-price-elasticity ϕ to vary across provinces as we expect different degrees of integration of local markets. The resulting model has an R^2-statistic of 71.7 percent and an adjusted R^2-statistic of 63.5 percent.

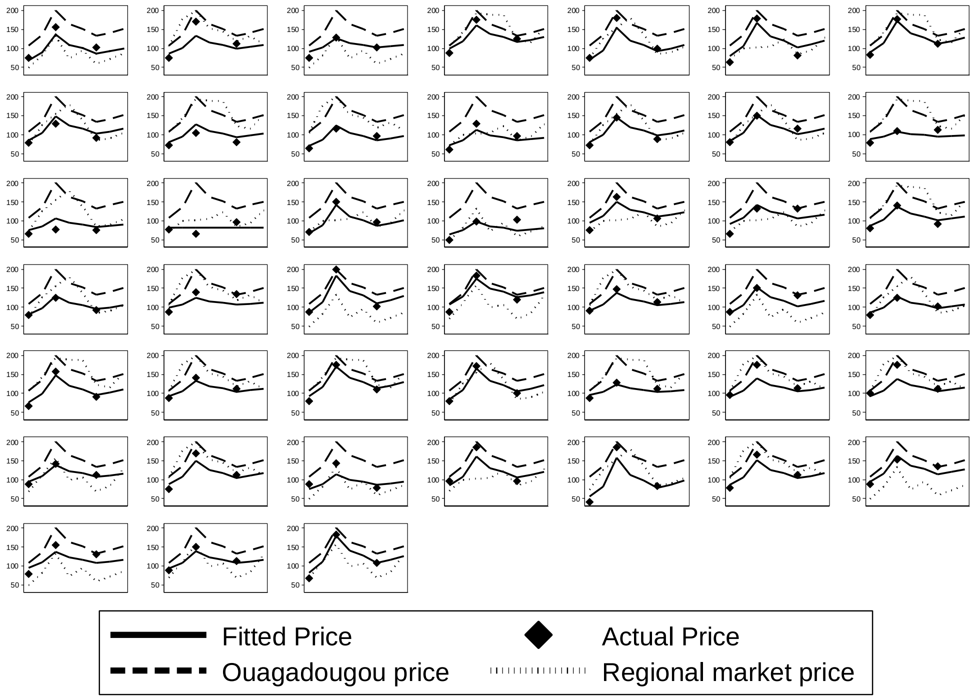
Appendix C1a: Predicted vs. actual prices for Sorghum, Millet, and Maize; May 2004, May 2005, and November 2006



Source: Authors' calculations based on PNGT data together with price data from INSD (2012)

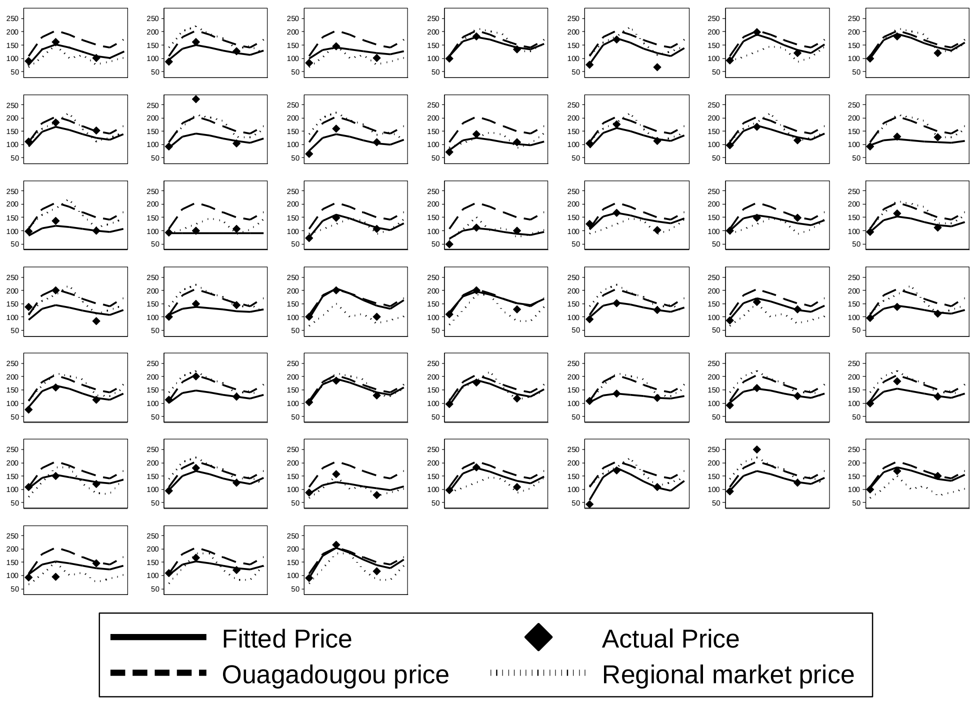
Appendix C1a plots predicted prices against actual prices. While there are some outliers (i.e. deviations from the 45-degree-line) in the sense that the actual price was much higher than the predicted price, the overall fit seems reasonable. Appendices C1b and C1c plot time series of predicted prices and prices in Ouagadougou for each province separately for sorghum and millet, the main staples in Burkina Faso, respectively. Also displayed are the actual province-level price observations from the PNGT data. Regional market prices are added for comparison. As one would expect for locally produced goods, the movement of our predicted prices track the price movements in Ouagadougou closely yet prices are lower and less volatile in the provinces.

Appendix C1b: Actual, imputed, and nearest large city-, and capital city-prices for Sorghum, May and November 2004, 2005, 2006, and 2007



Source: Authors' calculations based on PNGT data together with price data from INSD (2012)

Appendix C1c: Actual, imputed, and nearest large city-, and capital city-prices for Millet, May and November 2004, 2005, 2006, and 2007

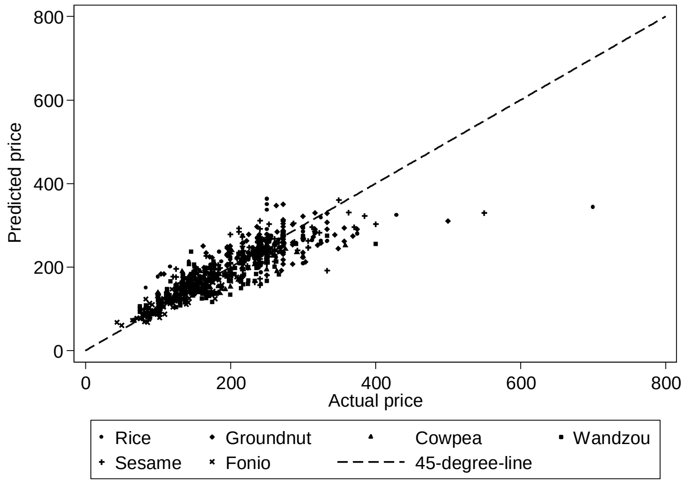


Source: Authors' calculations based on PNGT data together with price data from INSD (2012)

In a second step, we regress log prices from the three PNGT datasets on capital city-log prices for Sorghum and Maize and a set of province-fixed effects for all remaining crops separately.

These crops and the respective R^2-statistics are rice (40.3 percent), groundnut (41.3), cowpea (57.2), wandzou (55.9), sesame (52.6), and fonio (83.9). Appendix C1d plots predicted against actual prices. Finally, prices for cotton are fixed as the state is the monopoly buyer of cotton.

Appendix C1d: Predicted vs. actual prices for rice, groundnut, cowpea, wandzou, sesame and fonio; May 2004, May 2005, and November 2006



Source: Authors' calculations based on PNGT data together with price data from INSD (2012)

Appendix C2: Levels of rainfall across Burkina Faso, 1970-2009

In this appendix we report results from analyzing time series data from eight rainfall stations across Burkina Faso for years prior to our study period. For the validity of our instrument in the empirical application of this paper, it is crucial that levels of rainfall neither exhibit significant trends over time nor that conditional on the long-term mean past observations provide any information about future rainfall. In that case, deviations of rainfall from its long-term mean will be orthogonal to permanent income; income associated with good rainfall will be transitory (see also Deaton 1997, p. 290).

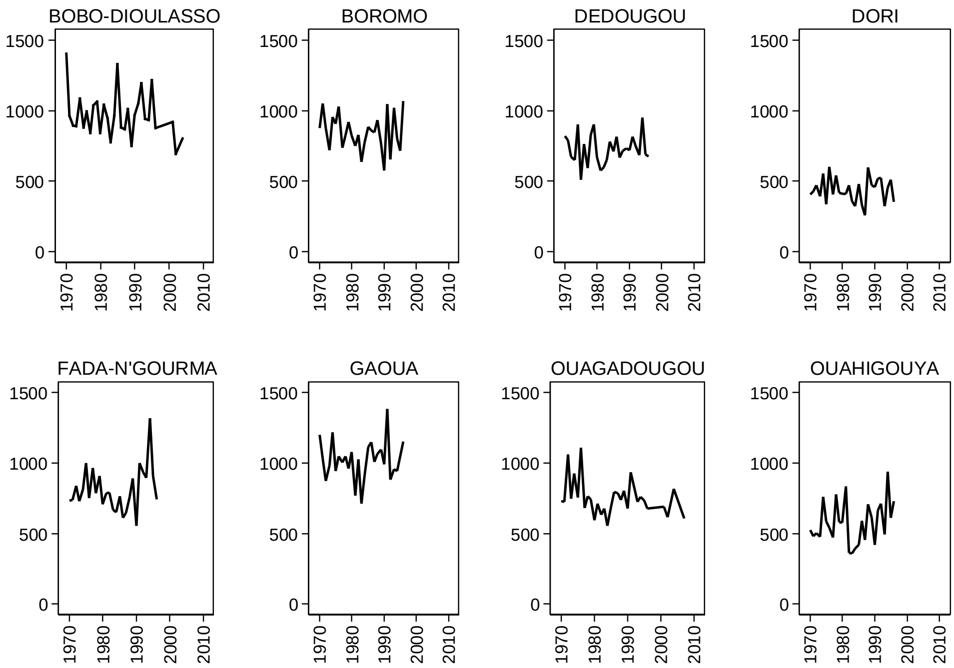
There is a long-standing tradition in development economics of using rainfall variability in order to distinguish between the effects of transitory and permanent income. Wolpin (1982) uses information on historical regional rainfall for rural Indian households assuming that households residing in regions with favorable weather conditions have higher permanent income. Paxson (1992) shows that the deviation of rainfall from its local mean is serially uncorrelated and thus unpredictable. It is therefore uncorrelated with permanent income yet in the context of unirrigated agriculture a strong predictor of transitory income.[100] More recent examples relying on

[100] She argues that "[i]n order to construct transitory rainfall variables [...], one needs to know how current rainfall deviates from its expected value. If rainfall were serially correlated across years, one would have to forecast the expected value of rainfall for each region in each survey year" (Paxson 1992).

rainfall in the WASAT region in order to compute transitory income include Fafchamps, Udry, and Czukas (1998), Kazianga and Udry (2006), and Carter and Lybbert (2012).

The data analyzed here come from FAO's *Climate Impact on Agriculture-website* (FAO 2014) and contain information on monthly rainfall collected by eight weather stations. To prepare the series for analysis, we first aggregate rainfall at the level of years, retaining only station-year-observations for which observations in each month were available. In a second step, we discard all stations for which we have less than 25 years of observations. The final time series are depicted in appendix C2a.

Appendix C2a: Rainfall levels recorded at eight stations across Burkina Faso, 1970–2009



Source: Authors' calculations based on data from FAO's *Climate Impact on Agriculture-website* (FAO 2014).

The location and elevation of these weather stations is reported in panel A of appendix C2b, where weather stations are sorted from left to right by latitude from south to north. Given the geographical locations of weather stations which capture much of the agro-climatic differences across Burkina Faso, the data allow us to make statements about rainfall patterns in very different parts of the country.

First, we subject the series to simple tests for linear and exponential time trends. We regress rainfall and log rainfall on years for each series separately. Results of this exercise are reported in panel B of appendix C2b. There is only one coefficient that is statistically significant at the ten percent-level, namely for the series from Ouagadougou. Second, we test for serial correlation.

Results from the Breusch-Godfrey-tests (see Godfrey 1978; Breusch 1979) are reported in panel C. The null hypothesis of no serial correlation is not rejected for any of the eight series.

Taken together, we conclude that there is no evidence that deviations of rainfall from its long-term mean are predictable based on observation of rainfall levels in the past. One can thus be confident that the deviations from long-term means (i.e. rainfall levels *conditional on household-fixed effects*) in rainfall levels are an appropriate instrument in the sense that they are orthogonal to permanent income.

Appendix C2b: Analysis of station-level rainfall data, 1970–2009

	Gaoua	Bobo-Dioulasso	Boromo	Fada-N'Gourma	Ouagadougou	Dedougou	Ouahigouya	Dori
Panel A. Location of weather stations								
Latitude	10.33	11.17	11.75	12.03	12.35	12.47	13.57	14.03
Longitude	-3.18	-4.32	-2.93	0.37	-1.52	-3.48	-2.42	-0.03
Elevation (m)	335	460	271	309	306	300	336	277
Panel B. Testing for time trends								
Coef.: rainfall on year	0.97	-4.21	-2.04	4.06	-3.78*	0.78	4.78	-0.38
	(3.70)	(3.07)	(3.29)	(3.80)	(2.15)	(2.64)	(3.63)	(2.22)
Coef.: log rainfall on year	0.00	-0.00	-0.00	0.00	-0.00*	0.00	0.01	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Panel C. Breusch-Godfrey Lagrange multiplier test for serial correlation								
F-value	0.308	0.454	2.539	0.678	0.005	0.894	0.000	2.474
p-value	0.584	0.506	0.124	0.418	0.944	0.354	0.997	0.128

Notes: Standard errors in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Sorted by latitude (rather than alphabetically). Based on data from FAO's *Climate Impact on Agriculture-website* (FAO 2014).

Appendix C3: Characteristics of households selling livestock

Appendix C3a tabulates means and standard deviations for households stratified by whether or not they have reported sales of cattle and of small livestock at any time in 2004–2007. Only about 44 percent of our households report sales of cattle. We also calculate differences and conducted regression-based *t*-tests (clustered standard errors in parentheses). We see that cattle-selling households are older, more likely to be headed by males, have more members, and are more likely to be residents of Burkina's Sahel region. The difference in average herd sizes is substantial: cattle-selling households own on average ten heads of cattle more than non-selling households. The picture that emerges for small livestock is very similar except that the proportion of households that has never sold small livestock is only about 20 percent.

Appendix C3a: Balance table comparing households that sold a particular type of livestock at some point between 2003 and 2007 to those that never sold

	Cattle			Sheep/Goats		
	Never sold	Sold	Difference	Never sold	Sold	Difference
Age of household head	50.75	52.20	-1.45***	50.38	51.63	-1.25**
	(0.37)	(0.40)	(0.52)	(0.62)	(0.30)	(0.62)
Male household head	0.91	0.98	-0.07***	0.90	0.95	-0.05***
	(0.01)	(0.00)	(0.01)	(0.01)	(0.00)	(0.02)
Household size	9.16	13.21	-4.05***	8.25	11.60	-3.35***
	(0.15)	(0.22)	(0.33)	(0.24)	(0.15)	(0.37)
Per hectare grain output (kg)	662.14	667.46	-5.32	690.54	658.16	32.38
	(7.54)	(8.05)	(20.24)	(14.07)	(5.93)	(24.17)
Per capita cultivated land (ha)	0.39	0.38	0.00	0.41	0.38	0.03
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.02)
# of cattle	1.30	11.61	-10.31***	1.77	6.85	-5.07***
	(0.07)	(0.79)	(0.98)	(0.21)	(0.45)	(0.59)
# of sheep/goats	8.42	20.33	-11.91***	3.41	16.18	-12.77***
	(0.25)	(0.61)	(1.02)	(0.25)	(0.38)	(0.75)
Sahel region	0.03	0.13	-0.10**	0.03	0.08	-0.06**
	(0.00)	(0.01)	(0.05)	(0.01)	(0.01)	(0.03)
# of total obs.		2,364			2,364	
# never sold		1,320			462	
# selling at least once		1,044			1,902	

Notes: Robust standard errors of means and differences in means clustered at the village-level and reported in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. The dataset is collapsed to obtain means over four years. Based on EPA data.

Appendix C4: Off-farm income and transfers

This appendix considers income diversification and substitution between different sources of income. We show that alternative income sources are unlikely to play an important role in households' risk management in our sample. We employ the PNGT data to that end as it records (gross) incomes from sources other than farming and livestock in much detail. Our results suggest that, first, the share in the total of income other than farming and livestock herding is small in most regions and that, second, income from these sources is positively correlated with crop profit over time.

In addition to crop profit and net sales of livestock as defined above, our data allow us to calculate (gross) revenues from households' non-cropping enterprises, net transfers, wages earned, and use of credit. However, crop profits account for more than 50 percent of the total in eleven out of 13 provinces. Only in the Centre-Nord region and in the Sahel is the share smaller. Trading in livestock is important in these two regions accounting for slightly less than one-fourth of the total. Revenues from own businesses are the second most important source of income according to this graph. However, as noted above, we are likely to overestimate their importance. Net transfers and wages earned working outside the family farm are negligible in comparison.

To investigate whether alternative sources of income become important in case of an adverse shock to crop output, we run regressions of these alternative income sources, net transfers received, revenue from own business, and wages earned on crop profit. The results are reported in appendix C4a. Since we are interested in partial correlations once time-invariant variables are controlled for, all regressions include household-fixed effects.[101] Every other regression also includes a year-fixed effect and further controls that capture the households demographic make-up.

Appendix C4a: Estimates of the effect of transitory crop profit on other forms of income (both in 1,000 CFA and per capita)

	Revenue from business		Net transfers		Wages		Credit	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crop profit (1,000 CFA)	0.15*	0.86	-0.01	0.03	0.01	0.13	0.03***	0.20
	(0.08)	(0.57)	(0.01)	(0.12)	(0.01)	(0.13)	(0.01)	(0.13)
Cragg-Donald F-statistic (weak identification test)								
F-statistic		11.91		11.91		11.91		11.91
# of obs.	2,946	2,922	2,946	2,922	2,946	2,922	2,946	2,922
# of groups	1,485	1,461	1,485	1,461	1,485	1,461	1,485	1,461

Notes: Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. All regression include a complete set of household control variables including the age, age squared, gender, and education level of the household head and indicators of the number of household members by sex and age. All regressions further include a full set of household-fixed effects. Based on PNGT data.

Results reported in appendix C4a indicate that there is no alternative source of income that would allow households to smooth consumption *ex-post*. While our data do not allow us to rule out that revenues from own business are an important source of income, there is no evidence for a negative correlation between this source of income and crop profit. In fact, the coefficient on crop profit is positive and significant in the OLS regression (column (1)), suggesting that if at all, revenues from own business will decline if crop profit does. As noted by Fafchamps, Udry, and Czukas (1998), the finding is also consistent with anecdotal evidence reported in Sen (1981) who argues that droughts often lead to a collapse in the demand for local services and crafts.

As expected given the low share of net transfers and wages in total income, the coefficients here are insignificant, both statistically and in terms of magnitude (columns (3)–(6)). We hence conclude that net transfers and off-farm labor play no important role in managing risks *ex-ante* for households in our sample. Our findings for credit use are similar in that the coefficients are positive (columns (7) and 8)).

[101] Since only two years of data are available from the PNGT dataset, this is equivalent to running the regression in first-differences.

Appendix C5: Testing exclusion restrictions

In section 3.7.1, we show that cattle prices are responsive to rainfall. This finding potentially threatens the identification strategy we pursue in savings regressions presented in section 3.6 – where we regress savings in the form of livestock on crop profit and instrument the latter with rainfall levels – since prices might also affect households' decision to purchase and sell livestock directly. In this appendix, we therefore aim to test directly whether our instrument can in fact be excluded from (3.5).

One way to test this, is to include the livestock and the price level of other goods, captured by the CPI, on the right hand-side of the equation of interest. Note that we are not suggesting that the resulting point estimates are in some way more valuable in judging whether households rely on livestock to smooth consumption. The hypothetical question of how household would react to transitory changes in crop profit *conditional on real livestock prices* is generally not of interest. Instead, we are solely interested in whether the identification strategy is valid. A significant coefficient on the log relative price of cattle should be interpreted as a sign that the exclusion restriction does not hold.

Results are reported in column (2) of appendix C5a. For comparison, we also report results from a regression without these prices in columns (1). This model corresponds to the one in column (2) of table 14 and is reported solely for comparison.[102] We cannot reject that the coefficients on log price of cattle and log CPI in column (2) are both individually and jointly zero.

One might also test exclusion restrictions directly based on Hansen's *J*-test. However, this requires more than just one instrument; the model needs to be over-identified. One would then be able to estimate the model employing a GMM-type estimator and test formally, based on Hansen's *J*-test, whether excluded instruments are orthogonal to the error process. One way of generating such additional overidentifying restrictions is to specify a set of instruments as in Holtz-Eakin, Newey, and Rosen (1988), where each time period of our panel is instrumented separately with rainfall and all off-diagonal elements of the instrument matrix are set to zero. We thus have a set of three instruments that convey information about rainfall in 2004, 2005, and 2006, respectively.

[102] The only difference is that we exclude households in three provinces, Boulkièmdé, Tapoa, and Loroum, in one year, 2005, for which there are no reports on livestock sales in 2005 and hence no lean season prices that we could calculate for 2004/2005. However, the resulting estimate is broadly in line with that reported in table 14.

Appendix C5a: Tests of over-identifying restrictions: net purchases of livestock (in 1,000 CFA)

	2SLS		GMM	
	(1)	(2)	(3)	(4)
Crop profit (1,000 CFA)	0.22*	0.27	0.21**	0.04
	(0.13)	(0.20)	(0.10)	(0.03)
Log price of cattle		-34.59		
		(43.42)		
Log CPI		93.94		
		(314.95)		
Year 2005	-18.94*	-28.75	-18.14**	-5.61
	(10.92)	(41.28)	(8.26)	(3.70)
Year 2006	-22.64*	-18.91*	-21.90**	-5.37
	(11.74)	(11.07)	(9.01)	(4.29)
Cragg-Donald F-statistic (weak identification test)				
F-statistic	18.62	9.75	14.96	9.86
Hansen/Sargan-test (over-identification test of all instruments)				
Degrees of overidentification	0	0	2	12
χ^2-statistic	0.00	0.00	1.43	8.73
p-value			0.49	0.73
# of obs.	6,857	6,857	6,857	6,857
# of groups	2,353	2,353	2,353	2,353

Notes: Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Net purchases of livestock and crop profit measured in 1,000 CFA. All regressions include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of household members in a total of eight gender-age cells. Based on EPA data.

A second option is to allow the rainfall to affect crop profit differently across Burkina Faso's 13 regions by specifying separate instruments for each region. The one column of the instrument matrix associated with a particular region then has all zero-entries except for those rows referring to observations in that particular region. This second approach results in a total of 13 moment restrictions that one can test. Both approaches convey slightly more information. However, it is the second approach that we think conveys most information as rainfall likely affects agricultural production differently across Burkina Faso's regions. It also resembles the approach taken in the literature more closely, in which rainfall is typically interacted with farm characteristics. In both cases, the additional moment conditions will be perfectly valid if rainfall itself meets the exclusion restriction.

Under the null, Hansen's *J*-statistic is χ^2-distributed with degrees of freedom equal to the degrees of over-identification – two and twelve with the instrument sets described above. It is consistent in the presence of heteroskedasticity and serial correlation. It should be noted, however, that the test is really a general specification test. If it is rejected, either the orthogonality conditions or other assumptions of the model or both are likely to be false (see Hayashi 2000, pp. 198–201 and 217–218, for details). In any case, a rejection will cast doubt on the appropriateness of the instruments employed.

Results from two-step efficient GMM-estimation are reported in columns (3) and (4). The degrees of freedom, χ^2-statistic, and *p*-value reported at the bottom of the table all refer to Hansen's *J*-statistic. The test statistics are sufficiently close to zero so that we cannot reject that our instruments are jointly valid (p-values of 0.49 and 0.73, respectively). We conclude that our instrument is rightly excluded from the estimation equation.

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