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Pathways from research on improved staple crop germplasm to poverty reduction for smallholder farmers

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ABSTRACT

Innovations to improve staple crop germplasm can reduce poverty and otherwise improve farmer livelihoods through complex and multiple pathways. This paper reviews the evidence for one prominent pathway—through increased incomes (in cash and kind) for poor farmers who adopt the technology.

An important determinant of poverty reduction is the ability of poor producers to adopt productivity-enhancing varieties, and the paper analyzes recent household-level data from two African countries to examine if poor producers face unique barriers to adoption. A second determinant of poverty reduction is the area available to plant these varieties and whether the intensity of adoption is great enough to significantly reduce poverty. The paper uses a double-hurdle estimation framework to model the adoption/area planted joint decision for maize farmers in Ethiopia and sweet potato farmers in Uganda. The focus of the analysis is the effect of poverty-related variables on adoption/area planted decisions. Farmer wealth, landholding, education, location, and access to support and information services are included to understand how correlates of poverty affect adoption decisions.

We find evidence that landholding size is an important barrier to poverty reduction; poor farmers are able to adopt improved varieties, but their intensity is constrained by land availability. In Uganda, farmers at the 95th percentile of adoption area received about \$0.13 per person per day from the incremental yield, covering < 50% of the mean household poverty gap. This gain only comes under optimistic assumptions and most adopters do not have sufficient area for the direct income effect to be large. The evidence suggests that direct, short-term impacts of increased productivity to increased income may be limited in magnitude. Nonetheless, we recognize that other, less direct pathways may be important, particularly over longer times. Impacts through indirect pathways are, however, more difficult to measure. This has implications for the design of M & E and the crafting of appropriate targets for outcomes of research on staple crops which should focus perhaps on the other pathways where poverty reduction is more probable.

1. Introduction

Staple crop research has traditionally focused on productivity gains with the idea that increasing the food supply would generate broad benefits. The Green Revolution (GR) showed that productivity gains following diffusion of modern varieties (MVs) moderated food prices with broad-based benefits accruing to society (Pingali, 2012; Evenson and Gollin, 2003). Pathways through which MV diffusion affect the rural poor are, however, complex and evidence of impact is conflicting. Information on poverty effects of MV diffusion on the rural poor will help justify increasingly competitive donor funding and facilitate research design.

In principle, staple crops research should be poverty reducing. As staples account for relatively large shares of food expenditures, moderating their prices should benefit poor consumers disproportionately. Consumption price effects on the poor play out on national and global scales, with much of the associated poverty reduction occurring over a long time horizon and distant from where the MVs are diffused (Christiaensen et al., 2011; Evenson and Gollin, 2003; Pingali, 2012). The challenges of scale and time complicate efforts to establish a causal relationship. In the face of growing demands for credible evidence on poverty reduction, international agricultural research centers (IARCs)

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have identified conceptual pathways by which agricultural research can reduce poverty. Analysis along the stages of these pathways will build the evidence base about linkages between agricultural research and poverty reduction.

Numerous pathways from agricultural research to poverty reduction exist; many are analyzed in this volume. Productivity growth lowers consumer prices (benefiting net purchasers), and expands employment by lowering nominal wages. Adopting farmers directly benefit from income gains, but these gains depend on the area under adoption and the size of the productivity gain relative to the decline in market price. Technology biases (such as labor savings) might free labor for supply off the farm or increase labor demand on the farm. Reduced or avoided losses from shocks to production allow marginal farmers to maintain their productive base and avoid sliding into poverty. Other indirect pathways include reduced malnutrition from consumption of more healthful foods, environmental enhancement, and empowerment of women.

Identifying a clear causal relationship between technology diffusion and outcomes or impacts is difficult. Several general principles apply. First, the shorter the pathway, the more convincing the linkage (e.g. yield or productivity benefits), but producing causal evidence even with very short pathways is complicated because adoption of MVs is not random. Second, with longer and more indirect pathways (e.g. impacts of adoption on household incomes, or on changes in household behavior), additional confounders complicate causal inference. Third, many factors falling outside the purview of agricultural research can attenuate poverty impacts of new technologies. For example, market institutions such as price controls mediate the effects of MV diffusion. Fourth, impacts on the poor depend on their characteristics (Are they engaged in agriculture? Do they purchase foods?) and the nature of the technology (Does it require large-scale investments? Are poor producers able to adopt?).

This paper has four objectives. First, it identifies pathways and linkages between germplasm improvement research on staple crops[1] and poverty reduction for smallholder farmers. Second, evidence is summarized with respect to what is known about the pathways. A substantial literature examines impacts of diffusion of MVs on poverty, with more recent research dealing with the vexing "evaluation problem" of measuring impacts in the context of endogenous adoption choices (Bezu et al., 2014; Diagne and Demont, 2007; Walker and Alwang, 2015). Third, evidence is presented on the shortest pathway: are the poor able to adopt MVs of staple crops? And, is this adoption likely to directly increase income by enough to affect poverty rates? Recent data from Uganda and Ethiopia are used to address these questions. These cases are illustrative; the obstacles to adoption and direct impacts on poverty reduction depend on idiosyncratic conditions and may vary by country. Fourth, we synthesize the evidence to help prioritize investments along the research-poverty pathway.

Recent literature shows that for small-scale farmers in rain-fed environments, income gains from adoption of improved technologies are not likely to be sufficient to lift farm families out of poverty (see Harris and Orr, 2014; Jayne et al., 2003). This failure is due to limited sizes of productivity gains and the relatively small areas over which adoption occurs.

Our paper complements this literature by focusing directly on obstacles to adoption and determinants of area planted. While large returns to adoption of agricultural technologies are frequently reported in the literature, widespread adoption is not the norm (deJanvry, 2016; Walker and Alwang, 2015). Heterogeneous agro-ecological conditions, absent markets for inputs and other factors create a puzzle whereby seemingly profitable technologies are not widely adopted (deJanvry, 2016). This paper examines whether poor farmers face obstacles to adoption and uses evidence from the literature and from two country cases to analyze these obstacles and their implication for technology-related poverty reduction.

We find that poor farmers face obstacles to adoption of modern varieties in some contexts, but the poor are not generally precluded from adoption improved germplasm. Instead, the bigger barrier to direct poverty reduction is small holding sizes of poor farmers. Adoption is spread over too little land to have a large effect on income even if yields of the improved varieties are substantially greater than the variety they replace. This finding is consistent with those of Harris and Orr (2014) and Jayne et al. (2003) and shows that the direct productivity pathway to poverty reduction is relatively minor. Other pathways such as through market price declines for consumers, or improved nutrition due to consumption of own-produced foods, are likely to be more important.

2. Conceptual framework

The conceptual framework begins with research on germplasm improvement to produce new staple crop varieties. We focus exclusively on varieties with attributes that aim to increase on-farm productivity through higher yields or increased resistance to major biotic (pests and diseases) or abiotic constraints (e.g. drought or heat tolerance). Resistance can also lower production costs by reducing the pesticide application. Yields can be enhanced by avoiding losses from production shocks or by a larger response of the crop to inputs.

The research process leading to varietal release includes several steps. Initial germplasm collection, conservation and characterization usually occur several years before research on varieties start. Breeders then select appropriate populations into the breeding process and generate candidates based on research objectives. Local and regional trials are conducted after candidate varieties are validated in on-station trials; regional trials test performance and stability under contrasting environments. Every country has a unique regulatory process and approval by national authorities is an important pre-release condition. Upon release, multiplication of seed (e.g. foundation or pre-basic, basic, registered or certified and commercial) by public and private institutions is necessary prior to diffusion. We assume these research components do not constitute a constraint. More often, however, they represent a large bottleneck to adoption, such seed systems that may be incapable of producing enough seed of the required quality. Extension systems and other diffusion-promotion methods can be weak or bypass certain populations. Policies such as input subsidies might be needed to promote adoption of new technologies (e.g. Ricker-Gilbert et al., 2011).

Following release, farmers with knowledge about and access to the technology decide whether to adopt the new varieties. Adopters need information about the characteristics of the new variety and information can be lacking or scarce in remote areas. The decision to adopt is based on the expected productivity increase and its variability with respect to current varieties. Farmers decide how much land to plant under the variety, subject to land availability and production objectives. Continued adoption depends on on-farm results and many technologies that perform well under ideal experiment-station conditions are not suitable in other conditions (deJanvry, 2016). In cases where complementary inputs such as fertilizer are needed, limited access to input markets and credit may slow adoption (Hazell and Haddad, 2001).

After the season, the crop is harvested and farmers sell output leaving a share for home consumption and seeds for next year, as appropriate. At this stage, several pathways of interest can lead to poverty reduction (Fig. 1). Immediate gains come from additional consumption and, if the MV is nutritionally fortified, nutritional benefits will emerge. If adoption is sufficiently widespread, supply increases in the market and drives down prices, reducing the share of income needed for purchasing food and increasing available income for other purposes. Net selling producers lose from this market price decline. If the variety is labor saving (e.g. less time spent spraying) it reduces on-farm labor use, freeing labor for other on-farm activities and off-farm employment. If a variety is labor-intensive on-farm labor use increases and poor farm laborers may benefit. Varieties with resistance to abiotic stresses also

[1] The focus of this paper is on research on germplasm improvement, acknowledging that many other forms of agricultural research (e.g. new management practices) also contribute to poverty reduction.

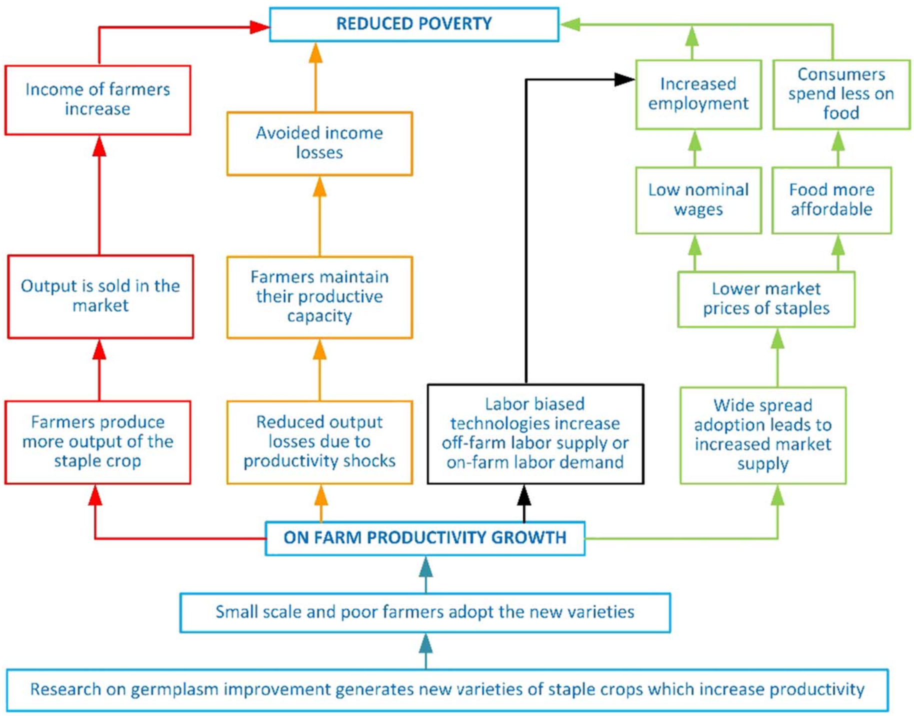

Fig. 1. Pathway from staple crop research to reduction of poverty of smallholder farmers.

limit yield and income losses when extreme climatic events occur.

These pathways reflect a limited part of the overall relationship between agricultural research and poverty reduction. A more granular focus on specific sub-pathways produces evidence that should be summed over all sub-pathways. The pathway of interest for the purpose of this study is the direct income effect through increased productivity (the leftward pathway in Fig. 1). The size of the income effect is proportional to the productivity effect (net of inputs) and the intensity of adoption (land area under cultivation with new varieties). We explore the conditions under which this effect leads to poverty reduction.

3. Critical summary of the literature

The pathway between modern variety (MV) release and poverty reduction is conceptually straightforward, but empirically validating the causal chain and its feedbacks is fraught with difficulty. This difficulty is related to the "evaluation problem". Since households are not randomly selected as "adopters" and "non-adopters" establishing a causal relationship between adoption and productivity or income growth is a challenge (Bezu et al., 2014; Diagne and Demont, 2007). This difficulty is compounded by the dynamics of adoption. Lags between variety release, adoption, and longer-term outcomes make it difficult to attribute the research to the ultimate outcome (Walker and Alwang, 2015). Furthermore, individual households may adopt incrementally, or alternate periods of adoption and disadoption, complicating the attribution of sustained economic impacts.

The paper begins with an analysis of the literature on the Green Revolution — the dramatic increase in wheat and rice yields beginning in the late 1960s resulting primarily from diffusion of MVs (Pingali, 2012). In the GR, achieving the yield potential of MVs was conditioned on the supply of complementary inputs, particularly inorganic fertilizer. Impacts of this diffusion are widespread,[2] have evolved over decades, and have been the focus of numerous studies. A challenge facing this literature is the difficulty of attributing outcomes to MV adoption.

The literature on the relationship between household economic status and adoption and diffusion of staple crop MVs is covered next. Next, the paper summarizes literature relating adoption to higher-level (but still within the household) effects—impacts on farm income, consumption, and household well-being. Evidence is next summarized about labor markets and whether MV adoption affects labor use or demand for hired labor. Labor markets are thought to be a major pathway to poverty reduction (Evenson and Gollin, 2003).

3.1. Evaluations of the green revolution

Early criticism of the GR held that large farms, due to better access to irrigation water, purchased inputs, and credit, were able to adopt new technologies relatively rapidly. Operators of smaller farms, who adopted later or not at all, were thought to be hurt by market price declines. Input prices may have increased for later adopters to their disadvantage. Green Revolution technologies were presumed to be labor-saving and diffusion was thought to lower employment and wages in rural areas. These factors led to perception that diffusion of GR technologies exacerbated poverty (Hazell and Haddad, 2001; Pinstrup-Anderson and Hazell, 1985).

Subsequent analysis, however, revealed nuanced impacts. In many regions, adoption by smaller-scale farmers was slow, but they were able to catch up over time and benefit from productivity gains. The production environment—land quality, agro-ecological conditions, and access to infrastructure—was more important determinant of adoption than farm size (Pinstrup-Anderson and Hazell, 1985; Prahladachar, 1983). Investments in infrastructure, particularly roads and irrigation, were leveraged by the MVs, and these indirectly contributed to poverty reduction, complicating the attribution of GR effects (Evenson et al., 1999; Fan et al., 1999; Johnson et al., 2003). Input subsidies helped poor farmers take advantage of GR technologies even as input prices rose (Pinstrup-Anderson and Hazell, 1985). Access to credit affected MV uptake, so poorer farmers who lack access due to limited collateral or other factors may have been disadvantaged (Hazell and Haddad, 2001). Farmers in less-favored environments may have suffered due to

[2] A large literature examines environmental impacts of the GR. These impacts have been mixed; the GR technologies saved land from being converted into agricultural use, but GR-related changes in water use, inputs and soil degradation have had negative consequences (Pingali and Rosegrant, 1994). A review of environmental impacts is beyond the scope of this study.

market price declines for their outputs as GR technologies were targeted toward favorable agro-ecological areas (Evenson and Gollin, 2003; Hazell, 2010; Pingali, 2012). If agro-ecology is correlated with the distribution of poor producers, targeting GR technologies to favorable areas could bypass the poor.

3.2. Aggregate evidence

Studies have linked staple crop research to poverty reduction at different levels. Some studies document the estimated yield gains globally due to diffusion of GR technologies (Cassman and Pingali, 1995; FAO, 2004; Pingali, 2012) and note that in the absence of these yield gains world food prices would be far higher than current levels (Evenson and Rosegrant, 2003). Poor consumers, for whom staple foods constitute a large share of food expenditures, benefit disproportionately from these price declines and food price moderation is known to have been a major engine of global poverty reduction (Evenson and Gollin, 2003; Pingali, 2012).

Several studies use cross-country or panel data to estimate growth-poverty "elasticities"—the percentage change in poverty given a change in agricultural productivity. These generally find a large poverty elasticity for agricultural growth and higher elasticities for agriculture than for growth in other sectors (Christiaensen et al., 2011; Ravallion and Datt, 1996; Thirtle et al., 2003). Ravallion and Datt (1996) show a 1% increase in agricultural value added in India leading to a short-run decline in poverty of 0.4% and a long-run decline of 1.9%. The latter fall comes primarily through indirect effects of lower food prices and higher wages. Chen and Ravallion (2007) find agriculture has four times larger poverty impacts than other sectors in China. Using large multi-country (n = 82) dataset, Christiaensen et al. (2011) find that agricultural growth has an especially strong impact on poverty reduction in low-income countries. Alene and Coulibaly (2009), using data from 27 African countries, find that income growth in agriculture is more effective in reducing poverty compared to growth originating in other sectors. Comparing across regions, agricultural growth-poverty elasticities are higher in sub-Saharan Africa than in developing countries in Asia and Latin America (Alene et al., 2009). Loayza and Raddatz (2010) suggest that the labor intensity is important in determining how sectoral growth contributes to poverty reduction. Growth in highly labor-intensive agriculture is the most poverty reducing of all sectors. All such studies take agricultural productivity growth as a starting point; the linkage between MV generation and productivity growth is assumed. But, evidence shows that agricultural growth, whether stimulated by diffusion of MVs or not, is a strong engine of poverty reduction.

3.3. MV adoption by poor farmers

Even a basic question such as "can the poor adopt MVs?" is difficult to answer. Adoption may have occurred long in the past so current adoption by poverty status may confuse the outcome (households who adopted long ago are no longer poor) with the cause. Poverty measurement requires detailed expenditure or income data, and these data are not always available in farm-household surveys; where they are available, if measured conterminously with technology usage, they are potentially endogenously related to technology decisions. Because of this complication, inferences about the household poverty-MV adoption relationship are usually based on land holding and asset ownership. Evidence also shows that the poor have less access to credit, lower levels of formal education, and less good information; these factors are often associated with less adoption of MVs.[3]

Empirical evidence shows that low-resource smallholders are generally not precluded from adopting improved staple varieties (Heisey et al., 1998; Morris, 1998; Smale, 1995). Large-scale farmers adopt relatively early in the diffusion process, but small-scale farmers can benefit from information gained from neighboring farmers and adopt over time. They thus avoid fixed costs of testing and can adopt with less uncertainty. In Africa, where hybrid maize was initially distributed through private seed networks to large-scale farmers, evidence of success quickly spurred demand by smallholders (Heisey et al., 1998).

Matuschke et al. (2007) find that holding size is not an impediment to adoption of hybrid wheat in India, but access to credit is. Higher income households and those with more information are also more likely to adopt. Thus, small landholdings per se do not constrain adoption, but poverty and conditions associated with it (no credit, poor information) may preclude the poor from adopting. Find farm size, access to information and credit, and household income are positively associated with farmer willingness to pay for hybrid seed, evidence of constraints to adoption by the poor (Matuschke et al., 2007). Diagne and Demont (2007) and Kijima et al. (2008) find farm size is not a significant determinant of adoption of NERICA (New Rice for Africa) in Cote d'Ivoire and Uganda, respectively. Diagne and Demont (2007) find access to information to be significant in the adoption decision, but do not link adoption to household poverty. Kijima et al. (2008) find measures of asset and livestock wealth are not significant determinants of adoption. Kijima et al. (2008) find no poverty-related variable to be a significant determinant of area planted to MVs.

Bezu et al. (2014) examine the relationship between household attributes and adoption and intensity of adoption of hybrid maize in Malawi using a Cragg double-hurdle model. Landholding size and education have positive impacts on the probability of adoption and on area planted. Poor farmers are less likely to benefit from hybrid maize adoption. Further, area planted is positively associated with household income, consumption and asset ownership. Households in the poorest wealth quintiles experience increased consumption of own-produced maize and the increase is (in percentage terms) higher for the poorest. Thus, poorer households may be less likely to adopt, but, once they adopt, they benefit.

Sorghum and millet are usually found in unfavorable environments where many poor farmers reside. The adoption question turns to what precludes any farmer from adopting an MV (Camara et al., 2006). There is little evidence in the literature of factors specifically affecting the ability of poor producers to adopt, but adoption of improved sorghum and millet is often dependent on availability of complementary inputs. Yield advantages of these two crops only emerge in the presence of inorganic fertilizers, improved water retention, and enhanced soil quality (Ahmed et al., 2000). Wubenhen and Sanders (2006) found that farm size was not an obstacle to adoption of improved sorghum varieties in Ethiopia and smaller-scale farmers were, in fact, more likely to purchase inorganic fertilizers. Timu et al. (2012) find that farm size is not statistically related to adoption of improved sorghum in Kenya, but more education, non-livestock assets and better access to extension are positively associated with adoption. Factors associated with poverty other than landholding may limit adoption. Pray et al. (1991) find that small-scale farmers in India were able to adopt sorghum and millet MVs. A comprehensive review of studies in West Africa show that supply factors such as the seed system and access to complementary inputs are major obstacles to adoption and the main farmer-specific factors are consumption properties and preferences for them rather than socioeconomic status (Camara et al., 2006).

3.4. Household-level impacts of adoption

Several studies employ a treatment effects approach to examine the relationship between MV adoption and outcomes such as income or expenditures and how changes in the outcomes affect measures of poverty. Matching, instrumental variable (IV) techniques, or use of

[3] In a wide-ranging review of the wheat adoption literature, Dixon et al. (2006) state that factors positively associated with adoption of wheat MVs include the level of education of the farmer, the resource base (assets and land), availability of credit and availability of information.

panel data help circumvent the "evaluation problem". The focus of these studies on intermediate (higher-level) outcomes complicates inference: differences in incomes and expenditures may be due to unobserved factors and the pathway between adoption and the outcome may be confounded by such factors. Adoption and area under the variety mediate higher-level indirect impacts.

Dontsop Nguezet et al. (2011) show, using matching techniques, that adoption of NERICA rice in Nigeria is associated with an almost 50% increase in incomes and expenditures. Smale and Mason (2014) find that adoption of hybrid maize in Zambia is associated with positive intermediate outcomes including household income, assets, farm equipment, livestock and an indicator of household poverty. They also find a negative association between adoption and poverty, but do not examine pathways (i.e. maize productivity) by which the outcomes result. Mathenge et al. (2014) conduct a similar analysis of hybrid maize in Kenya using panel data. Adoption is positively associated with education, access to extension, and farm size, providing some evidence that poorer households are less likely to adopt the new variety. Adoption is positively associated with income and asset ownership and negatively associated with household level poverty. They do not discuss the relationship between the income gain associated with hybrid maize adoption and the poverty line. Most studies do not examine impacts of adoption on farm- or plot-level productivity. Unless a technology saves substantial labor, gains in productivity are necessary for incomes to grow or assets to be accumulated. When a longer-term outcome such as asset accumulation is linked to technology adoption, verifying impacts on productivity helps build the study's credibility.

Khonje et al. (2015) use panel data from Zambia to estimate the determinants of uptake of hybrid maize and the impact of adoption on crop incomes, consumption expenditures and measures of food security. Household assets, education, and information (including extension visits) are positively and significantly related to adoption, while rented land is not significant (total land is not included in the regression). Adoption is positively associated with crop income, consumption expenditure, and food security. The average treatment effect (on income) was multiplied by land area planted to hybrid maize; the household-level effect was US$36 (or less than $0.10 per household per day). The consumption increase from adoption was only $0.02 per person per day, very unlikely to reduce poverty. Despite this minor effect of adoption on consumption outcomes, a regression of household poverty status on adoption shows a significant effect.

Becerril and Abdulai (2010) find a weak positive relationship between land holding and adoption of hybrid maize in Mexico and no evidence that poor households are unable to adopt. Education and access to information through extension visits are also not significant. Adoption is associated with a substantial increase in per-capita consumption (between $15 and $19 per person per month). When applied to the Mexican poverty line, the consumption increment is associated with a 9–31% reduction in the probability of being poor. Shiferaw et al. (2014) find that adoption of improved wheat is positively related to farm size and access to information from extension agents, but livestock assets and education are not significant. Adoption is associated with improvements in food expenditure, food security and others.

Kabunga et al. (2014) find that education and farm size are positively associated with adoption of tissue culture bananas in Kenya, but assets are insignificant and access to information (through a social network) has a significant negative effect. Results provide evidence that the poor are less likely to adopt this technology. Estimates of impact on higher-level outcomes (incomes and food security) show a strong positive impact on income (> 110%!) and a negative effect (also very large in magnitude) on food insecurity.

Mendola (2007) finds landholding and ownership of productive assets to be positively related to adoption of high yielding rice in Bangladesh. Education has no significant effect. Technology adopters are 14% less likely to be poor than non-adopters. The subsequent analysis of the effects of adoption on income and poverty outcomes shows clearly that income effects are stronger for households with larger landholdings; adoption helps the relatively well off by far more than it helps the poor. Adoption, however, reduces poverty among the lower land-owning classes, but has no effect on the near-landless poor. In the latter case, adoption increases their incomes, but not enough to lift them out of poverty.

Harris and Orr (2014) conduct a systematic review of literature on improved technology (not just germplasm) for dryland farmers. They use studies reporting or enabling calculation of net returns (income) associated with technical improvements. Their data on net returns are often from experimental fields and reflect the combined effect of the variety and well-managed inputs such as fertilizer and irrigation. They compute income gains for various landholding sizes assuming that the household obtains the experimental mean increment to net income per land area. This income gain is compared to international poverty lines, and even with the very high returns from adoption (30 of the 56 studies cited increases in net returns of 100% or more—four reported gains of > 1000%!) reported in the studies, income gains are insufficient to substantially reduce poverty.

3.5. Labor-market effects

Many MVs are, at least potentially, labor-saving technologies. Herbicide-tolerant (HT) maize varieties, for example, reduce labor use due to avoided manual weeding. Similarly, insect-resistant (Bt) varieties may reduce pest-control labor requirements. In a study of the labor impacts of HT maize in South Africa, Gouse et al. (2016) find evidence of net reductions in labor allocated to crop production (and evidence that labor savings were greater for women than men). However, while reporting qualitative evidence that some labor savings enabled casual off-farm labor market participation (for men), they did not quantify these labor market effects or their impacts on household welfare status. Van den Broeck et al. (2017) show that income gains from technology-related increases in off farm employment lower poverty by more than the direct on-farm income effect. In this case, however, the technology in question was adopted by large-scale farms and labor market spillovers were large. We know of no other studies that have quantified the poverty impacts through labor market linkages when technology is targeted toward smallholders. This seems to be an under-researched area, given the potential impacts on household economic outcomes.

The impacts of labor-saving technologies on labor market participation have been evaluated for other types of agricultural technologies. For example, Ahmed and Goodwin (2016) find that mechanization significantly enables non-farm employment in Bangladesh. They do not examine household income or poverty outcomes conditioned on labor market participation. While such impacts may be generalizable to other labor-saving technologies (including staple crop MVs), more empirical work is needed to determine this.

3.6. Conclusions from the literature

The literature is mixed on whether poor farmers are less able to adopt MVs. When landholding or wealth is included in regression models, coefficients tend to be only weakly significant and relatively small in magnitude. However, many variables that are often associated with poverty tend to associate significantly with adoption. In particular, access to credit and information are positive and significant in many studies. Landholding size is important in some studies, but not universally, and most studies fail to adequately link the findings on the magnitude of the effect with average (or the distribution of) holdings among the poor. Thus, the landholding effect is rarely analyzed with respect to holdings of the poor.

Linkages between adoption and improvements in higher-level outcomes are generally confirmed. But, in general, the incremental value of additional production due to adoption of MVs is relatively small at population means; poor farmers do not have adequate land to translate productivity gains into large enough income gains. This confirms the findings of Harris and Orr (2014) who come at it from the reverse-how much land, given yield/income effects, would be necessary to reduce poverty?

As land becomes increasingly scarce in Asia and sub-Saharan Africa, the poverty-reducing impacts of MVs of staple crops through direct income effects are likely to diminish Jayne et al. (2003). This is not to say other pathways are not important even in the face of modest direct income gains. Poor laborers with small holdings can gain if technology leads to increased demand for labor. Nutritional pathways may be less dependent on holding size; for example, small areas of high nutrient varieties may provide adequate nutrients, especially if the foods are targeted to nutrient-deficient populations.

Paradoxically, when the relationship between adoption and household poverty is examined, estimates often show a relatively large reduction in poverty associated with adoption even when adoption is spread over limited areas. Such magnitudes are not likely to be realistic given the accompanying relatively small direct effects and suggest potential problems with clean identification. Short-run poverty-reducing income gains depend almost entirely on productivity gains on the farm. Asset accumulation or other factors might allow adopting farmers to have larger income gains than suggested by the productivity effect, but it is incumbent on the researcher to identify the relationship. With small increments to productivity on limited areas, asset accumulation can only occur over an extended time. In addition to these points, the poverty rate is a population construct; most decision makers are interested in impacts on the population as a whole. Studies often report impacts of direct income gains on poverty among the population of farmers (growing a specific crop) and often among the population of technology-adopting farmers. Even relatively large decreases in poverty of the (targeted) sub-population will often be associated with far less reduced national (or even rural) poverty.

An important conclusion from the foregoing review is the following: Evaluations of the relationship between poverty and MV adoption should emphasize not just obstacles to adoption in absolute terms (e.g. access to credit), but also the effects of poverty-related variables on area planted to MVs, as the magnitude of household-level economic impacts is fundamentally mediated by the area extent of technology adoption on the farm.

4. Evidence from DIIVA datasets

The relationship between MV and direct poverty reduction for small-scale farmers depends on: (i) the position of poor farmers with respect to the poverty line; (ii) ability to adopt; and (iii) the area over which adoption occurs combined with the reduced per-unit cost of production from adoption. The latter factor measures the change in (full) income associated with adoption. Market prices may fall with widespread diffusion of improved varieties, so that poverty reduction reflected by (i–iii) reflects an upper bound on the poverty effect. Other indirect effects such as nutrition gains and rural intensification can be equally or more important than direct effects, but these effects are beyond the scope of this paper.

Factors ii and iii are examined using household datasets collected as a part of the Diffusion and Impact of Improved Varieties in Africa project (DIIVA; see Walker and Alwang, 2015). These data are nationally representative of maize producers (in Ethiopia) and sweet potato producers (in Uganda) and contained detailed information about specific varieties, areas planted, yields and other outcomes, input use and individual and household characteristics. Because the sampling was representative of producers of specific commodities, the datasets contain far more usable observations than others such as the LSMS-ISA, conducted by the World Bank. While the LSMS data are notable in the care taken to identify varieties and have a panel component, the relevant number of observations in the DIIVA datasets are far greater and tests showed no farmers had no difficulty identifying improved maize or sweet potatoes. A panel was not necessary to conduct our analysis. The surveys were conducted in 2011–12 by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with the Ethiopian Institute of Agricultural Research (EIAR) and the International Potato Center (CIP), the International Center for Tropical Agriculture (CIAT), HarvestPlus, and Virginia Tech in Uganda. Zeng et al. (2015) and Larochelle et al. (2013) provide details on sampling.

4.1. Data: Uganda

Uganda is among the top five producers and consumers of sweet potatoes in the world, and research devoted to this crop had focused on yields, dry matter, and resistance to biotic stress. Since the mid-2000s, the breeding focus shifted to nutritional concerns, and several varieties with high β-carotene, the nutritional precursor to Vitamin A, were released. Between 1995 and 2010, 19 improved sweet potato varieties were released in Uganda (described in detail in Larochelle et al., 2013). Since most of the improved sweet potato varieties were bred for increased yields, they represent a good illustration of direct income-related poverty reduction. The sample contains observations from 1578 sweet potato-producing households.

4.2. Data: Ethiopia

Maize in Ethiopia stands first in total production and second, next to *tef*, in area coverage (CSA, 2014). Over the last two decades, the average maize productivity has been increasing and reached 3.4 t/ha through strong linkages between agricultural research generating high yielding improved varieties and the agricultural extension system supporting the wider use of modern varieties with chemical fertilizer (Abate et al., 2015). Since the early 1970s, > 60 improved maize varieties were released/registered by the national system (Abate et al., 2015) and selected varieties were multiplied and distributed to their best fitting agro-ecologies. Data were generated from 1253 sample households growing maize in 30 maize potential districts of four regional states representing 93% of the national maize production (Zeng et al., 2015). Plot and household level data were collected.

4.3. Empirical model

We examine whether resource-poor farmers are able to adopt and, if so, whether they can adopt over sufficient area to generate income needed to overcome their poverty gap. Information is used on landholding, asset wealth, and other factors reflecting household well-being to explore the poverty/adoption/intensity relationship.[4] We first examine whether households who are asset poor are less able to adopt, then examine area decisions.

A double-hurdle (Cragg, 1971) framework is employed; this framework incorporates the idea that the decision to adopt a new variety results from two sub-decisions: the first hurdle determines whether the decision maker would ever adopt, and the second determines the intensity (area) of adoption. In comparison to the Tobit model, a frequently used alternative, the double-hurdle model allows variables to affect the adoption and area (intensity) decisions differently (Ricker-Gilbert et al., 2011). The decision to adopt the MV is a binary function based on its net profitability compared to the alternative.[5] Let π_{MV} and π_O be the expected profit from adopting and not adopting, respectively. The household adopts if $(\pi_{MV} - \pi_0) > 0$. The latent variable for household i's decision to use modern varieties is specified as:

[4] Due to unobserved factors affecting both outcomes, a regression of determinants of adoption or area planted including a right-hand side variable reflecting household poverty status would suffer from problems of disentangling causality.

[5] The alternative are non-improved sweet potatoes (those released prior to 1995) and non-improved maize, mostly local varieties or others released prior to 1998.

$$MV_i^* = x_{1i}'\beta_1 + \varepsilon_{1i} \quad (1)$$

Where the vector x_{1i} reflects determinants of this calculus, β_1 are parameters, and ε_{1i} is a normally distributed error term with mean zero and constant variance. The corresponding probit is estimated on the observed outcome $MV_i = 1$ if $MV_i^* > 0$ and 0 otherwise.

Desired area planted to MVs is also an unobserved latent variable:

$$A_i^* = x_{2i}'\beta_2 + \varepsilon_{2i} \quad (2)$$

Where x_{2i} are determinants of area, β_2 are parameters and ε_{2i} is a normally distributed error term. Since A_i^* is a latent variable, we work with observed area (A_i). Observed area $= A_i^*$ if $MV_i^* > 0$ and $= 0$ if $MV_i^* \leq 0$. Because we use observed area, the error term is a truncated normal distribution. The parameters β_1, β_2 can be estimated separately because the Cragg likelihood function is separable; the marginal effects, however, need special attention (Burke, 2009).

Agricultural technology adoption literature (Feder et al., 1985; Feder and Umali, 1993; Foster and Rosenzweig, 2010) indicates that adoption depends on socio-economic factors such as human capital, farm size, livestock ownership and labor availability; access to cash or credit; and agro-ecological conditions affecting productivity, among others. Farm size is may be correlated with factors influencing adoption such as wealth, ability to bear risk, access to credit and other inputs (Feder et al., 1985). Household labor availability can be an important determinant of adoption when the technology is labor intensive and hired labor is limited. Variables reflecting these factors are included based on availability from the dataset.

4.4. Results: sweet potatoes in Uganda

Controls for agricultural productive capacity are area cropped (ha), value of agricultural equipment owned (UGX), Tropical Livestock Unit (TLU), and the number of household members fully engaged in farming (Table 1). Other factors such as market access (distances to paved road and cities) are included. The 95th percentile of area planted to sweet potato and improved sweet potato in the sample is 0.452 and 0.294, respectively. The dataset does not contain sufficient information to measure poverty and we use proxy variables to reflect household economic status. In agrarian economies, land holding, livestock, equipment and asset ownership, and access to off-farm employment opportunities are positively related to well-being. Numerous studies have shown that the poor have less access to education and other public services such as extension, training and credit. We examine the marginal effects of these variables on the probability of adoption and area planted.

When regional dummy variables are excluded from the analysis (1st set of results in Table 2), wealth[6] has a positive and highly significant effect on the probability of adoption.[7] Households in the high wealth quintile are > 15 percentage points more likely to adopt than those in the low quintile (omitted group). Land holding also has a large positive association with adoption.

When regional dummy variables and ecological zone are included, the wealth and land variables are smaller in magnitude and not significant for the higher wealth quintiles (second set of results in Table 2). These results mean that wealth has a relatively small effect when unobserved regional factors are accounted for, with the upper two quintiles showing no statistically significant differences in the probability of adoption of improved sweet potatoes compared to the first quintile. Landholding size has a small positive association with adoption as an additional hectare of land in crops is associated with a three percentage point increase in the adoption probability. Variables reflecting household assets and livestock are not significant; education of the household head is also not significant. The coefficient of the dummy variable reflecting off-farm earnings is significant, but relatively small. More distant households are less likely to adopt improved sweet potatoes, but the magnitude is small: a 15 km increase in distance from a city (about one standard deviation) is associated with a 3.8 percentage point decrease in the probability of adoption.

Several regressors could plausibly be endogenous to the adoption decision. In particular, asset ownership, participation in agricultural organizations, credit uptake and off-farm labor supply decisions may suffer from endogeneity. To examine the robustness of findings, asset variables are excluded and the probit regressions are re-run. First, dummy variables reflecting off-farm employment, receipt of credit and membership in a farmer organization are deleted. Coefficients for remaining variables (including asset index quintiles) remain unchanged (less than a 10% change in the marginal effects and no change in significance). When asset variables (livestock ownership, farm asset and wealth quintile) are excluded, the remaining coefficients also do not change. These results, available on request, suggest that the potential problem of endogeneity does not affect model outcomes.

Considering adoption and area decisions jointly, wealth-related variables become more prominent, but the effects of these variables on area planted are relatively small (Table 3; full double-hurdle estimation results are shown in the Annex 1). Land and livestock holdings are not significantly associated with area planted to sweet potato MVs. As the value of agricultural equipment grows by one SD, 0.24 ha more are planted to MVs. Households in the 3rd-5th wealth quintiles plant about 0.05 additional hectares compared to those in the 1st quintile—the effect is significant but small in magnitude. Other indicators of wealth—credit access and off-farm income—are either not significant (credit) or small in size (off-farm income–0.028).

To examine poverty reduction from an alternative perspective, consider the potential gains in income from adoption and compare it to the shortfall of typical rural households below the poverty line. Use the formula $PG = H*A/Z$, where PG is the Foster, Greer, Thorbecke poverty gap, H is the headcount, A is the average income shortfall of the poor below the poverty line and Z is the poverty line. In 2013, using Uganda's official poverty line of approximately $1 US (PPP) per person per day, the rural PG was 6, and the national poverty H was 19.7 (World Bank, 2016). The mean shortfall below the poverty line, A/Z, is 30.4%, or $USD 0.304 per person per day. Sweet potato yields in Uganda are approximately 4.8 tons/ha on average and for this example we assume that improved varieties produce 50% higher yields. At the 95th percentile of adopters, 0.294 ha of improved sweet potatoes are planted. If the 95th percentile farmer obtained the 50% yield gain, an additional 0.71 t of production would be obtained from the improved varieties. At $US 0.33/kg (from community survey), this represents $232.85 per year, or $0.13 per person per day (mean household size in rural areas is conservatively estimated at 5, see World Bank, 2016, p. 19). Under these assumptions, the additional income from increased yield (not accounting for differences in production costs) would cover 43% of the income shortfall for the household at the 95th percentile of the adopted area distribution.

The picture from the analysis is that wealth is not a substantial constraint to adoption of improved sweet potato in Uganda. Some measures or correlates of wealth are statistically significant either in the adoption decision (area planted, lower wealth quintiles, secondary education of the wife), the area decision (value of agricultural equipment, higher wealth quintiles) or both (off-farm income). But, the overall magnitudes of these wealth effects are small and indicate that while wealth might be associated with higher likelihood of adoption

[6] The wealth variable includes household assets, such as durable goods, housing conditions and others. The wealth index reflects household well-being using durable goods ownership, housing characteristics, and type of sanitation and is constructed using polychoric principal component analysis (PCA) (Kolenikov and Angeles, 2009). Quintiles of the index are used to create dummy variables which are included in the regression model.

[7] There is clear potential for endogeneity of wealth to adoption; wealthier households may be more likely to adopt, and households may be wealthier because they adopted in the past. We argue for the former in this case, because we are using a definition of modern varieties as those released after 1998 so that the effect of short-term adoption on wealth is not yet likely to emerge.

Table 1
Variable descriptions and summary statistics, Uganda.

Variables	All Uganda (N = 1578)		Non-adopters (N = 1246)		Adopters (N = 332)	
	Mean	STD	Mean	STD	Mean	STD
Dummy (= 1 if adopt)	0.210	0.408				
Area under sweetpotato (ha)	0.132	0.158	0.125	0.160	0.160	0.146
Area under improved sweetpotato (ha)	0.017	0.059	0.000	0.000	0.080	0.107
Value ag equipment (UGX)	52,047	84,610	52,220	90,686	51,396	56,332
Total livestock units	1.539	2.698	1.502	2.626	1.676	2.953
Total land cropped (ha)	1.058	0.950	0.978	0.855	1.359	1.199
Number household members who farm	1.973	1.000	1.990	1.025	1.910	0.899
Respondent (= 1 if male)	0.817	0.387	0.827	0.378	0.777	0.417
Number children under 5	1.481	1.385	1.494	1.402	1.431	1.323
Number children 6–14	2.027	1.696	2.037	1.652	1.988	1.856
Adults	3.051	1.473	3.108	1.512	2.834	1.296
Education household head (dummy variables)	0.994	0.716	1.004	0.719	0.958	0.707
Education spouse (dummy variables)	0.866	0.630	0.823	0.614	1.024	0.664
Distance (km) nearest paved road	14.126	14.721	13.696	14.577	15.739	15.163
Distance (km) nearest city	26.940	13.177	27.741	12.610	23.934	14.752
Number households in village	148	103	137	84	192	149
Dummy (= 1 if member farm association)	0.151	0.358	0.155	0.362	0.136	0.343
Dummy (= 1 if household received credit)	0.093	0.291	0.105	0.307	0.048	0.214
Dummy (= 1 if household receives off-farm income)	0.435	0.496	0.407	0.491	0.542	0.499

Note: Education is coded as three dummy variables (not completed primary, not completed secondary and secondary and higher). Land cropped includes borrowed and rented in. The results are not sensitive to the land definition (that is including only owned land being cropped).

Table 2
Marginal effects for probability of adopting improved sweetpotato, Uganda.

Variable	Results 1: without region and eco_zone dummy variables				Results 2: with dummy variables			
	dy/dx	Std. err.	z	P > z	dy/dx	Std. err.	z	P > z
Eastern region					− 0.4082	0.0561	− 7.28	0
Northern region					− 0.4354	0.0558	− 7.8	0
Western region					− 0.2803	0.0841	− 3.33	0.001
Ecological zone 2					− 0.2603	0.0653	− 3.98	0
Ecological zone 3					− 0.3583	0.0967	− 3.7	0
Value ag equipment (UGX)	0.0000	0.0000	− 1.06	0.289	0.0000	0.0000	0.29	0.773
Total livestock units	0.0021	0.0043	0.49	0.621	0.0030	0.0030	1	0.317
Total land cropped (ha)	0.0644	0.0143	4.49	0	0.0312	0.0095	3.29	0.001
Wealth quintile 2	0.0947	0.0299	3.16	0.002	0.0668	0.0277	2.41	0.016
Wealth quintile 3	0.1047	0.0274	3.82	0	0.0525	0.0259	2.03	0.043
Wealth quintile 4	0.0876	0.0307	2.86	0.004	0.0214	0.0245	0.87	0.382
Wealth quintile 5	0.1553	0.0444	3.5	0	0.0278	0.0298	0.94	0.35
Head primary ed	0.0069	0.0368	0.19	0.85	0.0215	0.0291	0.74	0.461
Head secondary or higher ed	− 0.0600	0.0409	− 1.47	0.142	0.0081	0.0348	0.23	0.817
Spouse primary ed	0.0230	0.0214	1.07	0.284	0.0104	0.0193	0.54	0.588
Spouse secondary or higher ed	0.1051	0.0324	3.25	0.001	0.0908	0.0285	3.19	0.001
Male-headed	− 0.1003	0.0444	− 2.26	0.024	− 0.0722	0.0302	− 2.39	0.017
# HH members who farm	0.0213	0.0123	1.74	0.083	0.0128	0.0111	1.15	0.25
# children under 5	− 0.0057	0.0075	− 0.76	0.446	− 0.0023	0.0060	− 0.39	0.699
# children 6–14	− 0.0050	0.0053	− 0.94	0.346	− 0.0089	0.0043	− 2.06	0.039
# adults	− 0.0435	0.0111	− 3.93	0	− 0.0179	0.0090	− 2	0.045
Distance (km) to nearest paved road	0.0016	0.0014	1.17	0.241	0.0008	0.0008	1.07	0.287
Distance (km) to nearest city	− 0.0025	0.0019	− 1.33	0.183	− 0.0026	0.0011	− 2.34	0.019
Number households in village	0.0006	0.0002	2.79	0.005	0.0002	0.0001	1.09	0.275
HH member farm association?	− 0.0201	0.0259	− 0.78	0.438	− 0.0261	0.0225	− 1.16	0.247
HH received credit?	− 0.1049	0.0387	− 2.71	0.007	− 0.0410	0.0429	− 0.96	0.339
HH receives off-farm income?	0.0795	0.0239	3.33	0.001	0.0420	0.0200	2.1	0.036

and more area planted, the size of the effect is small enough to not be practically important. However, a back of the envelope calculation indicates that given small areas planted to sweet potato, the impact on poverty reduction is likely to be small even for farmers who adopt most intensively. Direct income effects of adopting improved sweet potatoes are small relative to the poverty gap, but are not negligible and can be part of a larger poverty reduction strategy. Nutrition benefits for pregnant women and children from OFSP can contribute to long-term reduction in poverty; these benefits do not depend on large planted areas.

4.5. Results: improved maize in Ethiopia

A wealth index developed from three asset-based indices (house type, durable assets and farm equipment owned) was used to evaluate how improved maize adoption and intensity of adoption are affected by household wealth. A significant proportion of wealthier households (quintile 4) are adopters and a larger proportion of the least wealthy group (quintile 1) are non-adopters (Table 4). Non-adopters are farther from main markets and cooperatives. Altitude, population density and rainfall are higher for adopters (Table 5). Adopter households have larger families and better-educated heads.

Table 3
Marginal effects from double-hurdle model—unconditional impacts of key variables on area planted, Uganda sweet potatoes.

	MFX	Std. err.	z	P > z
Eastern region	− 0.0520	0.0219	− 2.37	0.018
Northern region	− 0.0707	0.0657	− 1.08	0.282
Western region	− 0.0566	0.0208	− 2.73	0.006
Value ag equipment (UGX)	2.8200E-07	1.5900E-07	1.77	0.076
Total livestock units	0.0022	0.0038	0.59	0.555
Total land cropped (ha)	0.0060	0.0072	0.83	0.407
Wealth quintile 2[a]	0.0219	0.0225	0.98	0.329
Wealth quintile 3[a]	0.0535	0.0203	2.64	0.008
Wealth quintile 4[a]	0.0673	0.0237	2.84	0.005
Wealth quintile 5[a]	0.0534	0.0240	2.23	0.026
Male-headed[a]	− 0.0063	0.0155	− 0.41	0.684
# HH members who farm	− 0.0020	0.0079	− 0.25	0.801
Distance (km) to nearest paved road	− 0.0002	0.0002	− 0.83	0.406
Number households in village	0.0001	0.0000	2.52	0.012
HH received credit?[a]	0.0059	0.0185	0.32	0.746
HH receives off-farm income?[a]	0.0158	0.0068	2.32	0.02

[a] Indicates that the variable in question is discrete and marginal effect shows movement from base category.

Marginal effects from the double hurdle model (table 6) show significant differences in the likelihood and intensity of improved maize adoption for different wealth categories. Controlling for plot, household, and community level characteristics, and compared to better-off households (quintile 4), farm households in the three lower quintiles are less likely to adopt improved maize. Compared to better-off farmers, the likelihood of adopting is lower by 55.3, 25.1 and 34.2 percentage points for the 3rd, 2nd and 1st wealth index quintiles, respectively. Compared to better-off households, the improved maize area of quintile 1 and 2 households is lower by 0.53 ha and 0.27 ha, respectively. The probability of adopting improved maize is higher for households with better soil fertility, at higher altitudes, in areas with higher population density and with good rainfall. Households in high density areas have smaller farms but better access to infrastructure which encourages sustainable intensification through use of improved technologies. The intensity of adoption (maize area under improved variety) increases with family size and population density. The role of family size can be explained by increased labor availability to support adoption and by the consumption side where improved technologies could be used to secure adequate supply of maize for home consumption. Compared to Oromia (reference in the estimation), the likelihood of adopting improved

Annex 1
Double-hurdle results for Uganda sweet potato.

Variable	Adopt	Std. err.	z	P > z	Area planted		z	P > z
	Coef.				Coef.	Std. err.		
Eastern region	− 1.7128	0.1902	− 9.01	0	− 0.0885	0.0395	− 2.24	0.025
Northern region	− 2.1111	0.3181	− 6.64	0	− 0.0457	0.0974	− 0.47	0.639
Western region	− 0.8998	0.2832	− 3.18	0.001	− 0.1027	0.0536	− 1.91	0.056
Ecological zone 2	− 1.0341	0.2562	− 4.04	0	0.1670	0.0943	1.77	0.076
Ecological zone 3	− 1.5583	0.4564	− 3.41	0.001	0.1812	0.1065	1.7	0.089
Value ag equipment (UGX)	0.0000	0.0000	0.1	0.918	0.0000	0.0000	2.21	0.027
Total livestock units	0.0160	0.0161	0.99	0.32	0.0040	0.0036	1.11	0.266
Total land cropped (ha)	0.1675	0.0499	3.36	0.001	0.0104	0.0126	0.83	0.409
Wealth quintile 2	0.3491	0.1456	2.4	0.017	0.0371	0.0374	0.99	0.321
Wealth quintile 3	0.2786	0.1349	2.06	0.039	0.0906	0.0375	2.41	0.016
Wealth quintile 4	0.1198	0.1378	0.87	0.384	0.1138	0.0394	2.89	0.004
Wealth quintile 5	0.1404	0.1695	0.83	0.407	0.0897	0.0402	2.23	0.026
Head primary ed	0.1162	0.1570	0.74	0.459				
Head secondary or higher ed	0.0509	0.1874	0.27	0.786				
Spouse primary ed	0.0548	0.1025	0.53	0.593				
Spouse secondary or higher ed	0.4250	0.1313	3.24	0.001				
Male-headed	− 0.3432	0.1408	− 2.44	0.015	− 0.0113	0.0189	− 0.6	0.551
# HH members who farm	0.0639	0.0565	1.13	0.259	− 0.0035	0.0127	− 0.28	0.783
Number children under 5	− 0.0143	0.0319	− 0.45	0.654				
Number children 6–14	− 0.0445	0.0214	− 2.07	0.038				
Adults	− 0.0914	0.0446	− 2.05	0.04				
Distance (km) to nearest paved road	0.0040	0.0040	1.01	0.311	− 0.0007	0.0008	− 0.78	0.435
Distance (km) to nearest city	− 0.0137	0.0059	− 2.3	0.021				
Number households in village	0.0008	0.0007	1.13	0.259	0.0002	0.0001	1.61	0.108
Dummy (= 1 if member farm association)	− 0.1606	0.1277	− 1.26	0.209				
HH received credit?	− 0.2268	0.2406	− 0.94	0.346	0.0164	0.0436	0.38	0.707
HH receives off-farm income?	0.2266	0.1097	2.06	0.039	0.0484	0.0205	2.36	0.018
Intercept	1.1618	0.4254	2.73	0.006	− 0.0985	0.1232	− 0.8	0.424
sigma								
_cons	0.1568	0.0153	10.25	0				

Note: These are the regression results from which the marginal effects in Table 3 were computed.

Table 4
Summary of average maize area by wealth category, Ethiopia.

Variable	Quintile 1 (n = 424)	Quintile 2 (n = 342)	Quintile 3 (n = 195)	Quintile 4 (n = 292)	Total sample (n = 1253)
Adopter (1 = yes)	0.50(0.51)	0.55(0.50)	0.46(0.50)	0.60(0.49)	0.53(0.50)
Maize area (ha)	0.48(0.42)	0.52(0.39)	0.67(0.56)	0.71(0.63)	0.58(0.50)
Improved maize area (ha)	0.20(0.27)	0.24(0.30)	0.26(0.34)	0.32(0.34)	0.25(0.31)
Share of improved maize area	0.43(0.46)	0.49(0.47)	0.38(0.45)	0.50(0.45)	0.45(0.46)

Note: numbers in parenthesis are standard deviations.

Table 5
Summary of household and farm characteristics (Ethiopia, Maize).

Variables	All sample (N = 1253)		Adopters (N = 666)		Non-adopters (n = 587)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Adopter (1 = yes)	0.53	0.50	1.00	0.00	0.00	0.00
Maize area under improved variety (ha)	0.25	0.31	0.46	0.01	0.00	0.00
Wealth quintile 1	0.34	0.47	0.32	0.47	0.36[c]	0.48
Wealth quintile 2	0.27	0.45	0.28	0.45	0.26	0.44
Wealth quintile 3	0.16	0.36	0.13	0.34	0.18[b]	0.38
Wealth quintile 4	0.23	0.42	0.26[a]	0.44	0.20	0.40
Distance to market (minutes)	103.42	56.86	90.07	55.73	118.56[a]	54.31
Quality of road to market	2.27	1.40	2.30	1.33	2.23	1.47
Distance to cooperatives (minutes)	51.56	62.52	49.40	74.49	54.01[c]	45.18
Distance to extension (minutes)	30.85	30.94	31.66	31.57	29.94	30.20
Plot distance (walking minutes)	10.64	25.53	11.86[b]	31.29	9.25	16.67
Soil Fertility	2.46	0.56	2.45	0.55	2.48	0.57
Slope (1 = flat, 3 = steep)	1.52	0.69	1.46	0.63	1.59[a]	0.74
Soil depth (1 = shallow, 3 = deep)	2.21	0.82	2.24[c]	0.79	2.18	0.84
Altitude (m.a.s.l)	1869.24	288.77	1885.44[b]	307.83	1850.86	264.57
Population density	384.53	939.57	498.32[a]	1163.10	255.43	565.25
Rainfall	0.58	0.62	0.68[a]	0.68	0.46	0.53
Family size	6.45	2.30	6.58[b]	2.37	6.30	2.21
Sex of HHH	0.94	0.24	0.96[a]	0.19	0.91	0.28
Marital status (1 = married)	0.93	0.25	0.95[a]	0.21	0.91	0.29
Age of HHH	43.11	12.57	42.44	12.61	43.86[b]	12.49
Age square of HHH	2016.12	1190.14	1960.06	1185.90	2079.72[b]	1192.75
Education of HHH (years)	2.71	3.18	2.91[a]	3.33	2.49	2.99
Dummy literacy (1 = illiterate)	0.57	0.50	0.59	0.49	0.55	0.50
Dummy_Tigray (1 = yes)	0.04	0.20	0.01	0.08	0.08[a]	0.28
Dummy Amhara (1 = yes)	0.23	0.42	0.29[a]	0.45	0.15	0.36
Dummy_SNNPR (1 = yes)	0.13	0.34	0.18[a]	0.38	0.08	0.28
Dummy Oromia (1 = yes)	0.60	0.49	0.53	0.50	0.68[a]	0.47

[a] Significantly different from the other group mean at 1% level.
[b] Significantly different from the other group mean at 5% level.
[c] Significantly different from the other group mean at 10% level.

maize is relatively higher in Amhara and SNNP states. All three fall short of Oromia in adoption intensity.

Overall, adoption of improved maize varieties and the intensity of adoption is wealth specific. Households with fewer resources are less likely to adopt, and even if they adopt, their intensity is much lower than better-off farmers. Production benefits from the adoption of improved varieties depend on the level of yield gain, cost changes from technology adoption, and area allocated to the improved technology. Even if a farmer could double yield through the adoption of improved varieties, unless the area allocated to the improved technology is large enough, the yield increment may not guarantee a substantial improvement in household income. Thus, the impacts of improved technology adoption in agriculture is not equal for all adopters; better-off farmers benefit more that the resource poor ones.

Zeng et al. (2015) conduct an analysis similar to the calculation presented above for Uganda and found that poverty reduction from direct income effects was relatively modest. Assuming that consumer prices remain constant, the direct gain to producers from adoption of maize MVs is associated with a 1.7 to 3.1% drop in poverty among rural maize producers, a relatively modest reduction. In Ethiopia, the main obstacle to increased poverty reduction is land sizes of poor producers.

5. Summary and conclusions

This paper offers an overview of the multiple pathways by which research on modern varieties of staple crops impacts poverty status of rural smallholder households. Empirical evaluations of impacts along these pathways is complex. Where pathways are relatively shorter and more direct, e.g. welfare gains arising from farm income gains which may be directly associated with technology usage, self-selection and other sources of bias may confound impact identification. Continued expansion of experimental impact evaluation methods may help to address these weaknesses (although they raise other concerns such as external validity). Where impact pathways are longer and less direct, e.g. through impacts on labor markets or general equilibrium effects on national food prices, causal identification of technology impacts is challenged by the number, complexity, and interactions of conditioning factors over the time horizon required for indirect impacts to be felt. Nonetheless, these less-direct pathways are likely to have the largest aggregate impacts (Pingali, 2012).

Given the complexities in causal identification of poverty impacts, the empirical literature has been inconclusive about impacts of staples crops research on poverty outcomes in the developing world. Most assessments provide evidence that adoption of MVs is associated with improvements in household well-being. Poorer producing households do not face insurmountable obstacles to adoption and while wealthier producers adopt more readily and over a wider area, the poor do benefit. The main obstacles to greater poverty reduction include limited access to credit, services and markets and small landholding sizes of poor farmers. These factors are most consistently associated with lower rates of adoption of MVs.

The empirical results illuminate the magnitude of potential poverty impacts arising from direct channels, drawing on recent empirical evidence for sweet potato in Uganda and maize in Ethiopia. Our focus has been to present new evidence on the extent to which the rural poor are able to adopt MVs. The evidence indicates that poor producers do face higher barriers to adoption than the non-poor, but that these barriers are not large in magnitude. The poor are only marginally less likely to adopt technologies on average than the non-poor.

Consistent with Harris and Orr (2014) and other studies, the welfare impacts of MV adoption are limited by small land holdings. As a result, the direct effects of MV adoption on poverty reduction among smallholders are relatively minor. This result implies an important constraint on the direct welfare impacts of MVs even under optimistic diffusion

Table 6
Marginal effects of double hurdle model (probability and intensity of IMV adoption in Ethiopia).

Explanatory variables	Probability of adoption		Intensity of adoption	
	dy/dx	Std. err	dy/dx	Std. err
Wealth quintile 1[a]	− 0.342**	0.138	− 0.131***	0.038
Wealth quintile 2	− 0.251*	0.134	− 0.068*	0.036
Wealth quintile 3	− 0.553***	0.147	0.067	0.045
Plot distance (walking minutes)	0.002	0.002	0.001	0.001
Soil fertility	− 0.220**	0.088	0.023	0.024
Slope (1 = flat, 3 = steep)	− 0.029	0.078	0.005	0.021
Soil Depth (1 = shallow, 3 = deep)	0.106*	0.058	− 0.004	0.167
Altitude (m.a.s.l.)	0.000***	0.000	− 0.001***	0.000
Population density (person/km^2)	0.000**	0.000	0.001***	0.000
Rainfall	0.216**	0.099	0.040	0.027
Family size (number)	0.025	0.023	0.020***	0.007
Sex of HHH (1 = male)	0.405	0.343	0.005	0.095
Marital status (1 = married)	0.124	0.323	− 0.067	0.087
Age of HHH	− 0.055**	0.027	0.009	0.007
Age square of HHH	0.001*	0.000	0.000	0.000
Education of HHH (years)	0.021	0.024	− 0.001	0.006
Dummy literacy	− 0.023	0.148	− 0.046	0.039
Dummy_Tigray (1 = yes)[b]	1.770	6.362	− 0.954***	0.145
Dummy_Amhara (1 = yes)	0.631***	0.165	− 0.125***	0.046
Dummy_SNNPR (1 = yes)[c]	0.740***	0.244	− 0.151***	0.054
Mill's ratio			0.083	0.070
Distance to main market (minutes)	− 0.005***	0.001		
Quality of road to market (1 = poor, 5 = very good)	− 0.051	0.035		
Distance to cooperatives (minutes)	− 0.001	0.001		
Distance to extension service (minutes)	0.002	0.002		
Obs.	1253		1253	
LR Chi2 (21)	256.68		247.5	
Prob > Chi2	0.000		0.000	
Pseudo R2	0.148		0.048	
Log likelihood	− 737.68		− 816.36	

[a] Quintile 4 (better-off farmers in wealth) is the reference.
[b] Oromia Regional State is a reference.
[c] Southern Nations Nationalities and People Regional State.
*** Significant at 1% level.
** Significant at 5% level.
* Significant at 10% level.

and adoption scenarios. Another intuitively unsurprising result is that isolated farmers tend to have less access to MVs. This suggests that technology investments which explicitly target (shorter term) poverty reduction should be targeted to areas where the poverty density (poor people per area) is high. Higher density rural areas also have more potential to generate indirect spillovers such as through labor markets.

Results suggest that only modest reductions in rural poverty can be expected through direct effects. Poor adopting producers, because of small landholdings will experience limited income gains. In addition, producers of the crop may be only a small percentage of the total rural population, and adopters of the variety might be only a relatively small percentage of total producers. This is not to say that research on modern staple varieties does not reduce poverty, just that effects through other pathways are likely to be more important than direct pathways. Moderation of prices, reduced volatility of prices and supplies, and linkages to the non-farm economy all contribute to poverty reduction (and are likely more important than direct effects).

For some staples, e.g. orange-fleshed sweet potatoes, none of these pathways is likely to be the main engine of poverty reduction. Instead, consumption at home of modest amounts by malnourished children will reduce nutritional deficiencies and, over time, contribute to well-being. Pathways from improved nutrition though higher educational achievement to increased well-being as adults are complex, but their complexity says nothing about their importance.

A number of strategic research priorities emerge from our work. These include (a) the need to better measure productivity gains from MVs; (b) the need to focus on indirect (but still measurable) impacts, e.g. labor and product market effects, nutritional impacts and others; c) the continued need for credible identification, particularly of higher-level effects within the household; and d) the need to be clear that poverty reduction occurs over a long period of time. The final point reinforces the correctness of the impact pathway approach—assessment of poverty impacts should focus on validating the stages along the impact pathways and methodically build evidence of a causal relationship. This has implications for the design of M & E and the crafting of appropriate targets for outcomes of research on staple crops which should focus perhaps on the other pathways where poverty reduction is more probable.

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