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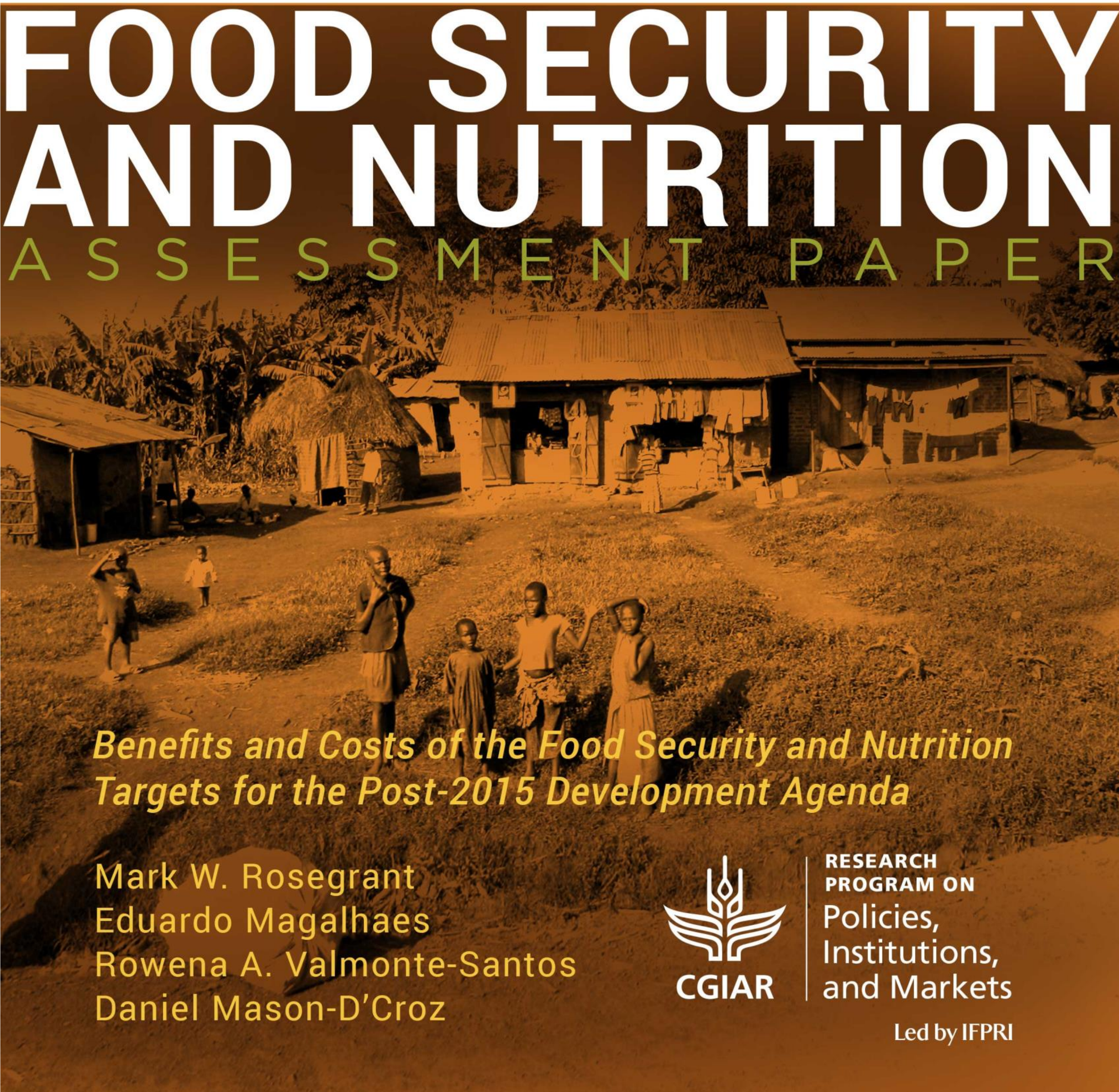

Benefits and Costs of the Food Security and Nutrition Targets for the Post-2015 Development Agenda

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Returns to Investment in Reducing Postharvest Food Losses and Increasing Agricultural Productivity Growth

Post-2015 Consensus

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Introduction

The 2008 and 2011 food price spikes sparked concerns about whether the growing global population would be able to feed itself in years to come, and with this came a renewed increase in interest in the level of postharvest losses (PHL) and the potential for reduction in PHL to improve food security (Kaminski and Christiaensen 2014; Zorya, Morgan, and Rios 2011). Addressing PHL particularly in developing countries, could play an important role in reducing the amount of production needed to feed this growing population (Beretta et al. 2013; Buzby and Hyman 2012). This resurgence in interest in recent years came 34 years after the World Food Conference held in Rome, Italy in 1974 and UN Resolution 271, which called for a 50 percent reduction in PHL in developing countries by 1985 in an effort to increase food security (Booth and Burton 1983; Boxall 2001). This prompted significant research and food loss reduction activities, and a number of national and regional loss assessments were carried out around the world. However, when commodity prices resumed their downward trend, policy emphasis shifted back to economic liberalization and trade for achieving food security (Zorya, Morgan, and Rios 2011).

The 2008-2011 food price spikes brought the issue of PHL back to the forefront of policy debate, and observers are again calling for a reduction in PHL as a tool to feed the expanding global population. Food losses due to improper postharvest handling, lack of appropriate infrastructure, poor management techniques, have once again become a matter of serious concern. Food losses, defined as "any decrease in food mass throughout the edible food supply chain", can occur in any point of the marketing stages–from production (e.g., crop damage, spillage), postharvest and processing stages (e.g., attacks from insect or microorganisms during storage), distribution, and retail sale until home consumption (e.g., spoilage, table waste) (Rosegrant, Tokgoz, and Bhandary 2013). Kummu et al. (2012) suggest an additional one billion people could be fed if food crop losses were halved, which could potentially relieve some of the pressure on the significant increase in production that would be required.

One way to address food security in developing countries is to ensure the inclusion of infrastructure development and technology improvements in postharvest best practices (Kitinoja and Cantwell 2010). However, the extent to which reductions in PHL can cost-effectively contribute to improved food security is far from clear in the literature. If PHL are in fact high and economically recoverable, targeting these losses could make significantly more food available, improve food security, and reduce overall food costs, which can make important contributions in fighting hunger and malnutrition and feeding the rising population especially in developing countries. Hence there is a need to understand the existing and potential investments and technologies that affect PHL and their cost-effectiveness in reducing PHL.

In this paper, we seek to better understand the levels of investment required to effectively reduce PHL. Doing so requires a series of steps. First, it is necessary to understand how infrastructure impacts losses. This can be done via econometric analysis (see section 3 for details). Given the diversity of regions and countries in the world, the gains obtained from reducing losses in the presence of infrastructure require that investments in infrastructure be made so that countries and regions can achieve desired levels of reduction in losses. The second step is to quantify the levels of investments required, which can be done by combining marginal effect analysis (based on the econometric estimation) with data on unit costs for specific infrastructural variables. Third and finally, it is essential to undertake a cost-benefit analysis of the required infrastructural investments to assess whether or not significant efforts in PHL reduction are economically feasible. This last step is done using the International Model for Policy Analysis of Agricultural Commodities and Trade developed by the International Food Policy Research Institute (IFPRI's IMPACT model).

This work begins by reviewing the evidence to date focusing not only on the magnitude of PHL but also on the suggested solutions to reduce it. The review presented in the two subsequent sections paves the way to the analytical work that follows. In particular, the review provides the rationale for analyzing the role of infrastructural variables on PHL after considering the issues that surround PHL and the technologies available to address these issues. The remainder of this paper is organized as follows. Section 2 describes the landscape of the research done on PHL and the diverging magnitudes of losses. It also provides a brief review of the impact of PHL-related technologies as well as the importance of infrastructure in addressing PHL and ensuring that technologies are adopted. Section 3 presents the methodological approach used in the econometric analysis as well as for the IMPACT model. Section 4 discusses the data and results. The paper ends with a brief conclusion and recommendations.

Postharvest Losses and Responses

Understanding the magnitude of losses

A large number of papers have been published on losses focusing mostly on four aspects of PHL: 1) estimates of the magnitudes of losses; 2) the economic impacts of losses in general but also on the poor and the hungry in particular (Gomez et al. 2011); 3) alternatives to decrease losses through the use of both new and traditional technologies; and 4) the economic costs of losses as well as their remedies.

Unfortunately, despite the large number of publications on the subject, there is little consensus on either the magnitude of the problem or the benefits of methods to reduce PHL. First, estimating the exact magnitude of losses is in itself far from being an exact science and a number of studies point to large inconsistencies in the published estimates. Even from a global perspective, estimates of total losses fall under a wide range (10-50 percent), which not only leaves room for ample ambiguity but have also, in some cases, been found to be based on old and outdated datasets. This lack of precision is compounded by a complete absence of impact measurement in important emerging economies like the BRIC (Brazil, Russia, India and China), for which no assessments have been made on the extent of food waste (Parfitt, Barthel and Macnaughton 2010). Global estimates would be extremely affected by PHL in any one of these countries.

This difficulty in measurement is felt particularly in developing countries where the problem of losses is the most severe. There are huge discrepancies and year-to-year variations even within estimates of specific crops in particular countries or regions. For instance, the African Post Harvest Loss Information System (APHLIS) is a network of cereal grain experts whose platform draws in estimates from national researchers. Their estimates of PHL in Sub-Saharan Africa are based on sets of PHL profiles and seasonal data. Estimates range from 10-20 percent, which is well below the 40-50 percent frequently cited in the development community but again are based on algorithms and figures derived from the scientific literature due to the lack of data available in most African countries (Zorya, Morgan, and Rios 2011; http://www.aphlis.net).

Estimates of rice losses in Southeast Asia, for example, range from 37-60 percent, while extreme cases in Vietnam are estimated to result in 80 percent of production being lost (Institution of Mechanical Engineers 2013). But a more comprehensive estimate for rice losses in Asia 13-15 percent, based on several studies reported in Parfitt, Barthel and Macnaughton (2010). Using self-reported measures from household surveys, Kaminski and Christiaensen (2014) estimated that on average between 1.4, 2.9-4.4, and 5.9 percent of the national maize harvest is lost in Malawi, Tanzania and Uganda respectively. Despite maize being more prone to PHL than other cereals (World Bank 2011), these estimates are much lower than the Food and Agriculture Organization (FAO's) estimate of 8 percent PHL in cereals in Sub-Saharan Africa (FAO 2011).

A related problem in the estimation of losses is their de-facto economic impact. Like the estimates of losses, economic impacts vary dramatically by region and country. In Africa, cereal losses amount to approximately US$ 4 billion out of a total production value of US$ 27 billion. Studies on China point to a figure of US$ 45 billion a year in rice-related losses alone (Tefera et al. 2011)). In Great Britain for instance consumers waste about £ 11.8 billion in entirely avoidable losses (Bond et al. 2013). In the United States (US), Buzby and Hyman (2012) estimate the economic value of food loss at the retail and consumer levels to be at US$ 165.5 billion in 2008 and point out that achieving a 1 percent reduction in food loss in the US would save US$ 1.66 billion.

Hodges, Buzby and Bennett (2011) estimate annual weight losses in Sub-Saharan Africa to be valued at around US$ 4 billion a year out of an estimated cereal production value of US$ 27 billion. They do, however, acknowledge that most PHL estimates in developing countries are based on questionnaires rather than actual measurements and explain that these estimates are calculated based on data from 16 countries in East and South Africa assuming rate would be similar in the rest of Sub-Saharan Africa. APHLIS estimates the value of PHL to be US$ 1.6 billion/year in eastern and southern Africa alone.

Part of the problem in reconciling all these studies is that not all losses are created equal. On-farm, value chain and consumer losses constitute entirely different problems in themselves, even if they are interrelated. In addition, within each of these types of losses sub-estimates can be found for losses which are avoidable and non-avoidable (Beretta et al.

2013). In Switzerland, for instance, the largest sources of loss comes are from processing and consumers, of which 2/3 are unavoidable[1].

One important factor to take into consideration in PHL discussion is how much of a reduction is actually feasible or realistic and at what cost these goals can be achieved. As part of the UN "Zero Hunger Challenge" announced in 2012, one of the five pillars to achieving this goal was to achieve zero food waste. De Gorter (2014) points out that not only is this target unrealistic and impossible to achieve in practice, but in terms of economic efficiency, the resources used to reach this level of PHL might better be used to eradicate hunger in other ways. Kader (2005) argues that a cost-benefit analysis is needed to evaluate the return to investment to find an acceptable level of loss for different commodities and environments rather than assuming that everyone should aim for 0 percent loss.

Technology and infrastructure

The quest for reduction in PHL is inherently linked to availability and profitability of technologies that can eliminate or reduce losses. Various technologies exist to help abate losses in the various stages of postharvest. The potential gains from adopting technologies need to be measured against the costs in adopting the technologies. Studies that look at the cost effectiveness of specific technologies to reduce PHL are not abundant, but provide insights into the questions that surround technology adoption.

A good starting point is to illustrate some of the potential gains from the various technologies (refer to Appendix Table 1 for technologies description). For example, on-farm technologies[2], adopting curing on roots, tubers and bulbs are lead to a return to a profit that is 2.5 times larger than the returns on non-adoption. Cooling practices used for vegetables can provide gains up to 7.5 higher than the initial costs. Other technologies such as shading have more limited gains, even though the adopter recoups the investment quickly. Gains for technologies at the value chain stage also vary in magnitude and in the time-span to recoup the investment. Two important factors have to be considered, however, in analyzing these gains. First, some of the technologies do require a fairly substantial amount of production (as well as increases in related inputs, such as labor) in order to be applied thus limiting the availability to small farmers. Technologies like metal silos may not require additional labor but are expensive to adopt, though the returns are high (Gitonga et al. 2013). Second, technologies such as improved packaging require additional costs in labor and in capacity building, which may reduce the overall profitability.

The key question however is whether the technology in question is adopted. Economically speaking, agents will choose to adopt a certain technology if the gains are greater than the costs. So why aren't these technologies being more widely adopted? The literature offers a

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1 Parfitt, Barthel and Macnaughton (2010) described avoidable food loss as the condition where wasted food or drink are consumable at some point before discarding (due to personal preference) such as fresh fruits, vegetables, dairy products. On the other hand, unavoidable food loss are those discarded parts of fruits, vegetables, meat or fish which are not consumable at any point under normal conditions.

2 This paragraph draws heavily from the analysis of Kitinoja (2010).

few insights to answer this. Producers are reluctant to change their modus operandis unless the losses are considerably higher than average (Greely 1982). This, in turn, suggests that the acceptable threshold of losses for producers is relatively high particularly if remedying the losses imply considerably higher costs.

Perhaps though the most telling reason for slow adoption or scaling up of potential PHL is found in Minten, et al. (forthcoming) and echoed in a number of other papers (Swaminathan 2006 as cited in Lundqvist et al. 2008; Kaminski and Christiaensen 2014) . Minten et al. (forthcoming) looks at cold storage practices in Bihar, India. They find that over recent years, the adoption of storage practices has increased significantly. Increases totaled 64 percent between 2000 and 2009, or 5.7 percent per year. The reasons for increased adoption, however, are the improvement of the physical and social infrastructure, which paves the way for producers to have access to profitable technologies. Not only have recent governments in the region put in place better public provision services and policy reforms, they have also invested in roads and infrastructure, thereby increasing the ability of farmers in remote areas to have access to markets. At the same time, the rule of law has improved in recent years, as have general governance practices. Kaminski and Christiaensen (2014) also point to the importance of education in reducing PHL. They argue that education combined with economic incentives such as easier access to markets via better infrastructure can significantly reduce losses. Others such as Parfit, Barthel and Macnaughton (2010) and Tefera et al. (2011) have also pointed to the growing need of improving infrastructure, particularly in rural areas, as a key instrument to reduce PHL. Tefera et al. (2011) in particular, points to the specific case of the adoption of metal silos in Kenya, whose benefits could be greatly increased if better rural infrastructure was provided. The findings listed above suggest that infrastructure is an important determinant of the levels of PHL and the potential for reducing PHL.

Methods

Grouped logistic regression

The relationship between PHL and infrastructural variables can be modeled using an Ordinary Least Squares (OLS) approach as issues of endogeneity are not present in a country level. The absence of endogeneity arises because the data on losses are collected or estimated at the producer level. For small farmers, particularly in developing countries, the infrastructure that surrounds the farm is therefore taken as a given and thus can be seen as exogenous. Even at the value chain level, firms in a given country also have to tap from the infrastructure that is provided.

The problem that arises from a standard OLS approach is the fact that the dependent variable is expressed as a rate (a percentage). This means that the variable is bounded between 0 and 1. As a result, fitted values obtained from the regression need to fall within this range, but the OLS provides no assurances that this will happen. Following an approach based on Wooldridge and Papke (1996), we have applied a weighted grouped logistic approach in which the logit transformation is applied to the dependent variable, as defined in equation (1).

$$\log\left(\frac{y_i}{1-y_i}\right) = \beta_0 + \beta_1 x_i + \varepsilon_i \quad (1)$$

Where y corresponds to the percentage of loss of in country i, β_0 is a constant, β_1 is a vector of coefficients for infrastructural, geographical, type of loss and crop variables in x in country i and ε is an error term. The transformation applied to the dependent variable ensures that fitted values fall between the specified 0 and 1. As specified the model becomes a logistic one, hence implying that the exponentiated coefficients on the right-hand side are to be interpreted as odds ratios. The model is estimated using weighted least squares.

A subsequent step after the estimation of equation 1 is to obtain the marginal effects of the significant variables in order to be able to compute the required levels of investments needed for a reduction in PHL. Predicted marginal effects were estimated by treating sequential points along the distribution of each of the significant variables as fixed while keeping all other variables at their means. This provided a number of points which could be mapped to show the relationship between losses and increases in selected infrastructural activities. By combining these results with unit cost data for each of the relevant infrastructures, we derived the required levels of investments needed to reduce losses by 5, 10 and 25 percentage points.

IFPRI's IMPACT Model

The International Model for Policy Analysis of Agricultural Commodity and Trade (IMPACT) is a partial equilibrium, multi–commodity, multi-country model which covers 56 crops and livestock commodities. It includes 159 countries/regions where each country is linked to the rest of the world through international trade and 320 food producing units (grouped according to political boundaries and major river basins). Demand is a function of prices, income, and population growth. Crop production is determined by crop and input prices, the rate of productivity growth, and water availability. The model uses a system of supply and demand elasticities incorporated into a series of linear and nonlinear equations, to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. IMPACT generates long-term projections of food supply, demand, trade, and prices that enable us to estimate the trends in global food security between 2010 and 2050 (Rosegrant and the IMPACT team 2012; Hoddinott, Rosegrant, and Torero 2013).

Food security indicators such as the percentage and number of malnourished children under the age of five and the population at risk of hunger are also computed in IMPACT. The percent of malnourished children is calculated using the relationship discovered by Smith and Haddad (2000) in a cross-country study. This formula is based on the observed impact of food availability, female education where female secondary enrollment rates serve as proxy, and equal access to health and sanitation where life expectancy, and access to safe water is used as proxy. The data used to make this calculation are obtained from: the World Health Organization's Global Database on Child Growth Malnutrition, the United Nations Administrative Committee on Coordination- Subcommittee on Nutrition, the World

Bank's World Development Indicators, the FAO FAOSTAT database, and the United Nations Organization for Education, Science and Culture (UNESCO) UNESCOSTAT database.

The share at risk is a share of the total population that is at risk of suffering food insecurity. This calculation is based on a strong empirical correlation between the share of malnourished within the total population and the relative availability of food and is adapted from the work done by Fischer et al. (2005) in the International Institute for Applied Systems Analysis (IIASA) World Food System used by IIASA and FAO.

The food security and economic impacts of investments to reduce PHL—and increased investments in agricultural research—are modeled here in IMPACT Version 3, newly updated in 2014. PHL reductions are represented in the model by equivalent increases in commodity yields. Four PHL scenarios were run to simulate the effects of potential improvements in harvest technologies, and transportation infrastructure that would allow for a larger percentage of what it planted actually reaching markets. The results for these PHL scenarios were compared to the impact of increased agricultural research investments. All scenarios were run using the Intergovernmental Panel on Climate Change (IPCC) medium projection on socioeconomics (SSP2), and assuming a constant 2005 climate. Table 1 summarizes the assumptions on socioeconomics for SSP2.

Table 1. Average annual growth rates (%) to 2050 for GDP, population, and per capita GDP by region under SSP2

Region	**GDP**[a]	**Population**[b]	**Per capita GDP**[c]
East Asia and Pacific	2.9	0.1	2.8
Europe and Central Asia	1.9	0.1	1.8
Latin America and Caribbean (LAC)	2.4	0.5	1.9
Middle East and North Africa (MENA)	3.6	1.1	2.4
North America	1.5	0.5	0.9
South Asia	4.1	0.7	3.3
Sub-Saharan Africa (SSA)	5.4	1.8	3.5
World	2.5	0.6	1.9

Notes:
[a] OECD GDP projections
[b] IIASA Population projections
[c] Calculated in IFPRI's IMPACT model
Source: SSP Database (https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about)

The following scenarios (Table 2) were then implemented to test the effects of potential decreases in PHL. Scenarios 1-4 follow the same specifications as the Baseline, except where described below. Note that a 10 percent reduction in PHL is defined as a reduction by 10 percentage points, for example from 20 percent PHL to 10 percent PHL. Additionally, a scenario with an increase of agricultural research and development (R&D) investment from US$ 5 billion/year to US$ 13 billion/year was included to allow for comparability of the benefits of investments decreasing PHL to the benefits of increasing agricultural R&D.

For this 5th scenario, we follow the assumptions made by Hoddinott, Rosegrant, and Torero (2013), where the effects of agricultural R&D would increase the yield growth for crops by 0.4 percent/year and livestock by 0.2 percent/year.

Table 2. Scenario summary

Scenario	Region	Commodities Groups and Postharvest Loss Assumptions	
		Less perishable commodities[a]	**More perishable commodities**[b]
Baseline (BSL)	Global	Standard IMPACT 3 yield projections	
Scenario1 (PL1)	Developing Countries[c]	By 2020: postharvest losses decline by 3% By 2025: postharvest losses decline by 6% By 2030: postharvest losses decline by 10%	
Scenario2 (PL2)	Global		
Scenario3 (PL3)	Developing Countries[c]	By 2020: postharvest losses decline by 1% By 2025: postharvest losses decline by 3% By 2030: postharvest losses decline by 5%	By 2020: postharvest losses decline by 4% By 2025: postharvest losses decline by 9% By 2030: postharvest losses decline by 15%
Scenario4 (PL4)	Global		
		Yield Assumptions from Investments in Agricultural R&D	
Scenario5 (AR1)	Global	Starting in 2015 All crops: exogenous yield growth increases by 0.4 percent per year All livestock products: exogenous yield growth increases by 0.2 percent per year	

Notes:
[a]Cereals, Pulses, Roots and Tubers, Oilseeds, and Other Crops
[b]Fruits, Vegetables, and Livestock products
[c]Excludes High Income countries: Australia, Canada, EU27, Israel, Japan, New Zealand, South Korea, Singapore, Switzerland, USA, and High Income Persian Gulf States
Source: Authors

Data and results

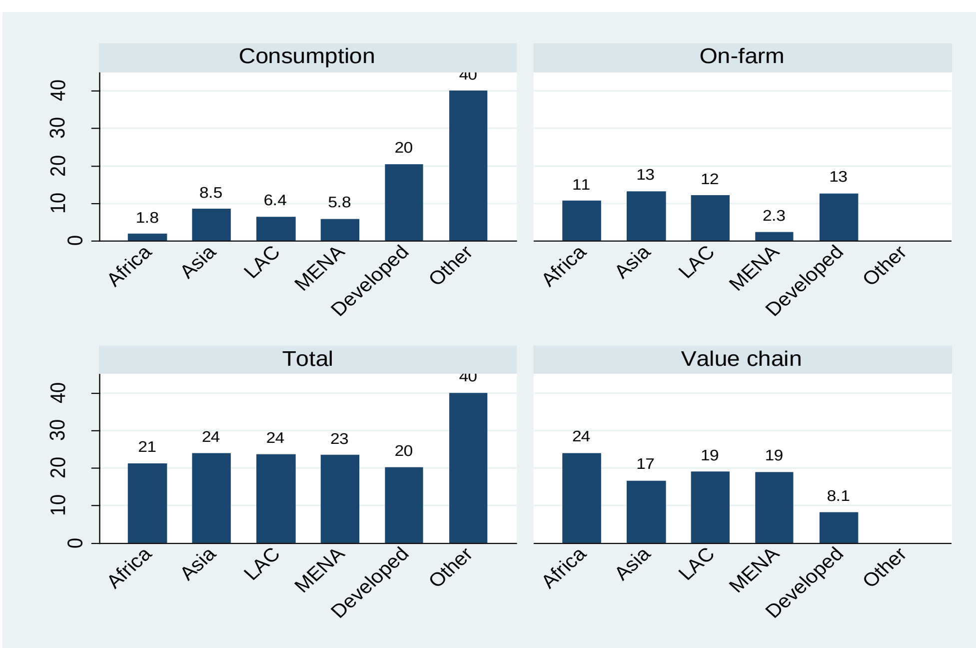
Losses

Data on PHL were drawn for a wide range of sources including APHLIS and a variety of published work on the subject (Appendix Table 2). In total, data for 40 countries and four aggregates were compiled (refer to Appendix Table 3 for description). The data were collected for four types of losses: on-farm, value chain, consumption and total losses. Losses were also further classified by region and by type of crop. In particular, the data contain information for the following regions: Developed countries, Africa, Middle East and North Africa (MENA), Latin America and the Caribbean (LAC), Asia and Others. Six commodity groups were identified: cereals, roots, oilseeds, fruits and vegetables, meat and dairy (henceforth referred as animal), and others. Some of the difficulties mentioned in the literature review about data quality were indeed found in the process of conducting work. The major issue relates to the time the losses occur, which for 50 percent of our sample was not identified. Out of the remaining 50 percent, 30 percent took place in 2007 and 2008. The remaining 20 percent was spread out between 1995 and 2012. For the years for which year information were available, data on infrastructural variables were matched to reflect the infrastructural conditions of that year. For observations without a specified year, an average of the 2000-2012 values of infrastructural variables was taken and combined with the loss dataset. Given these difficulties, we have conducted our regression analysis by treating the dataset as a cross-section.

The complete dataset on losses contains 818 observations. This dataset includes observations at both the country level and at subnational levels. However, due to the absence of infrastructural data at the subnational levels, the PHL data had to be aggregated to the national level in order to merge with the infrastructure data (see description of infrastructural data in the next section, below). The aggregated dataset contains 253 observations. The subsequent analysis conducted here and in the next section therefore uses the more aggregated dataset.

Figure 1 illustrates the average losses by type and by region. Regions display fairly different averages depending on the type of loss. For instance, while consumption and on-farm losses are higher in developed countries, value chain losses are higher in developing countries. Africa displays the highest average losses for value chain and the lowest for consumption, which is expected given the continent's lower incomes. For consumption and value chain, Asia, LAC and MENA show fairly similar averages. MENA's on-farm losses are considerably lower than the other developing regions, all of which observe average losses of around 10 percent. Total losses presented in the figure were obtained directly from sources and are not a result of our calculations (the same applies to the developed country averages). The largest total loss is for the group of countries called "Other" which include aggregates that did not fall under any classifications (including estimates on global losses). The developed world displays a low overall loss average compared to developing regions.

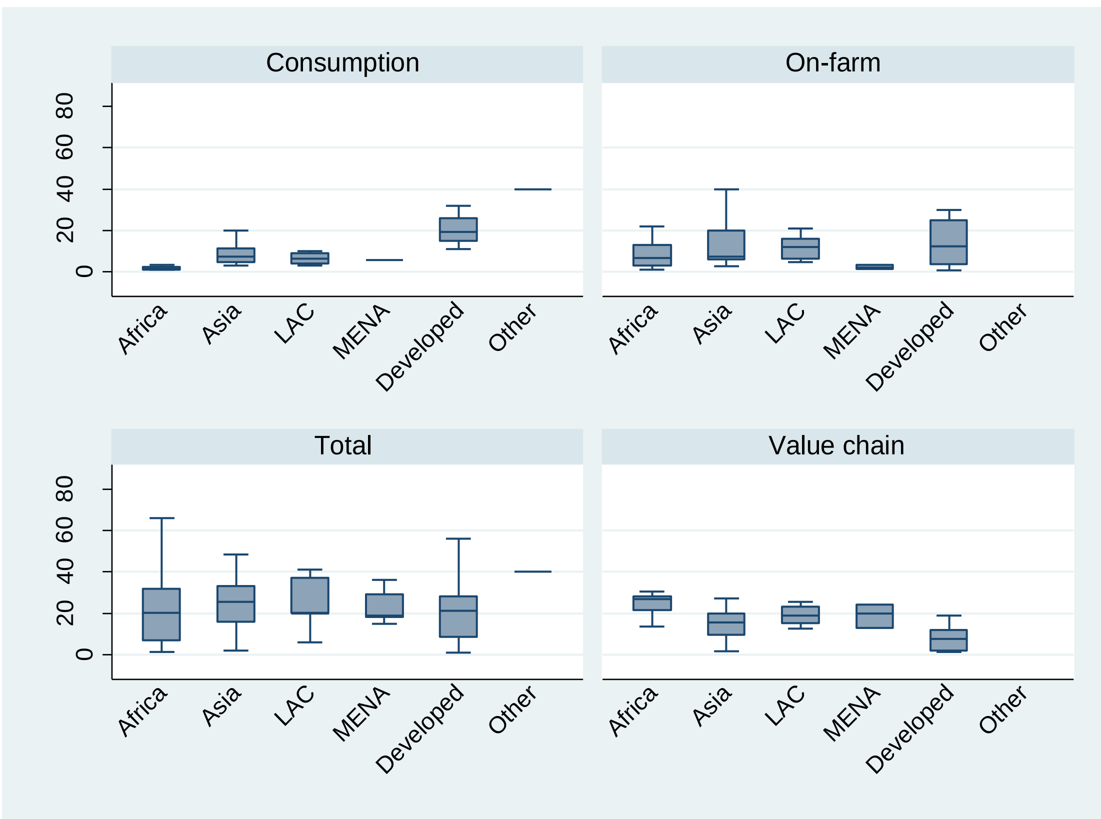
Figure 1. Average losses by region and type of loss



Source: Author's calculations using various sources.

Averages are illustrative but may mask considerable variation in the data. Figure 2 provides a more detailed look into the distribution of losses. The box plots displayed below contain bars that represent different moments in the distribution. The box in the middle is bounded by the 25th and 75th percentile and has the median displayed as a horizontal line inside of it. The whiskers show the end points of the distribution. The range of consumption losses in the developed countries is considerably higher than in developing regions, as would be expected. A large range is also observed for on-farm losses in the developed world. However, regions like Africa, Asia and LAC are not too distant from the median loss in the rich world. This scenario of higher losses in the developed world is reversed when value chain losses are considered. Not only does the rich world witness a much lower range, but also the median values for developing regions are considerably higher.

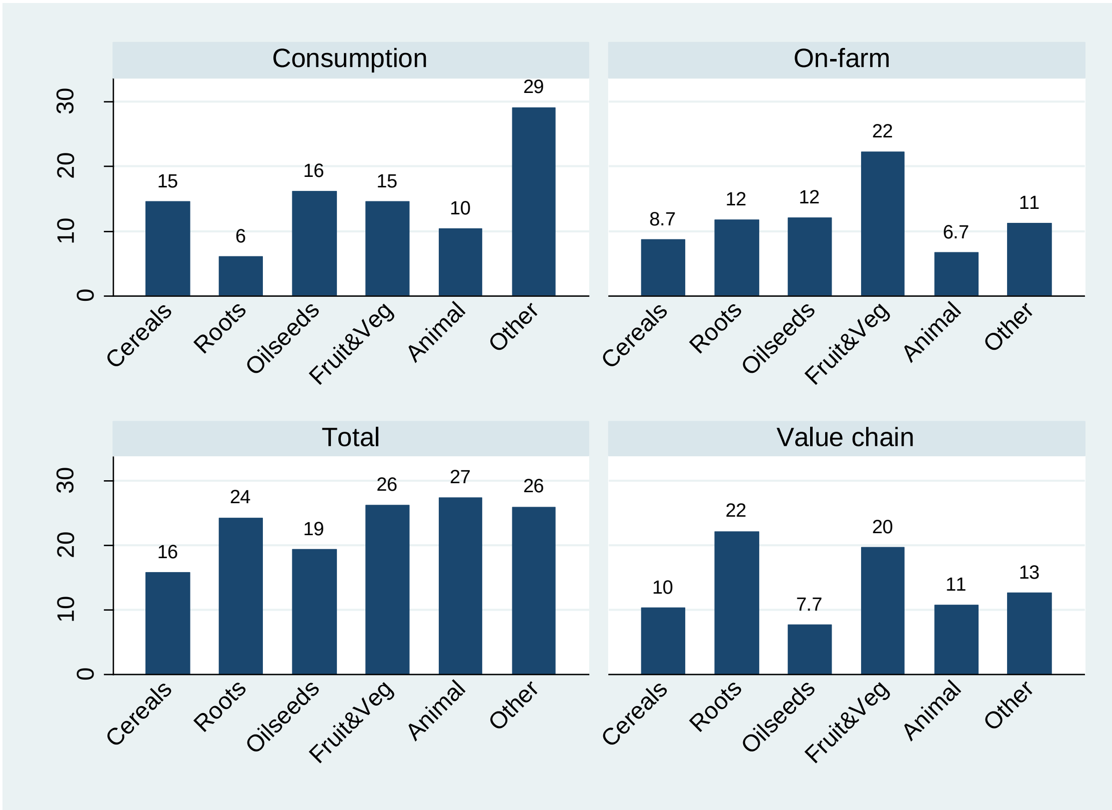
Figure 2. Box plots of postharvest losses by type of loss and region



Source: Author's calculations using various sources.

Figures 3a-b reproduce Figures 1 and 2 but replace regions by the type of crop. A few interesting aspects emerge from the figures below. First, fruits and vegetables dominate by a considerable margin the on-farm losses. Cereals, roots and oils seeds observed similar percentages. Losses are also large on value chain for fruits, as are for roots. On-farm losses by crop do not show much variation across commodity groups with the exception of losses originated from animal products, which observe significantly lower averages (Figure 3).

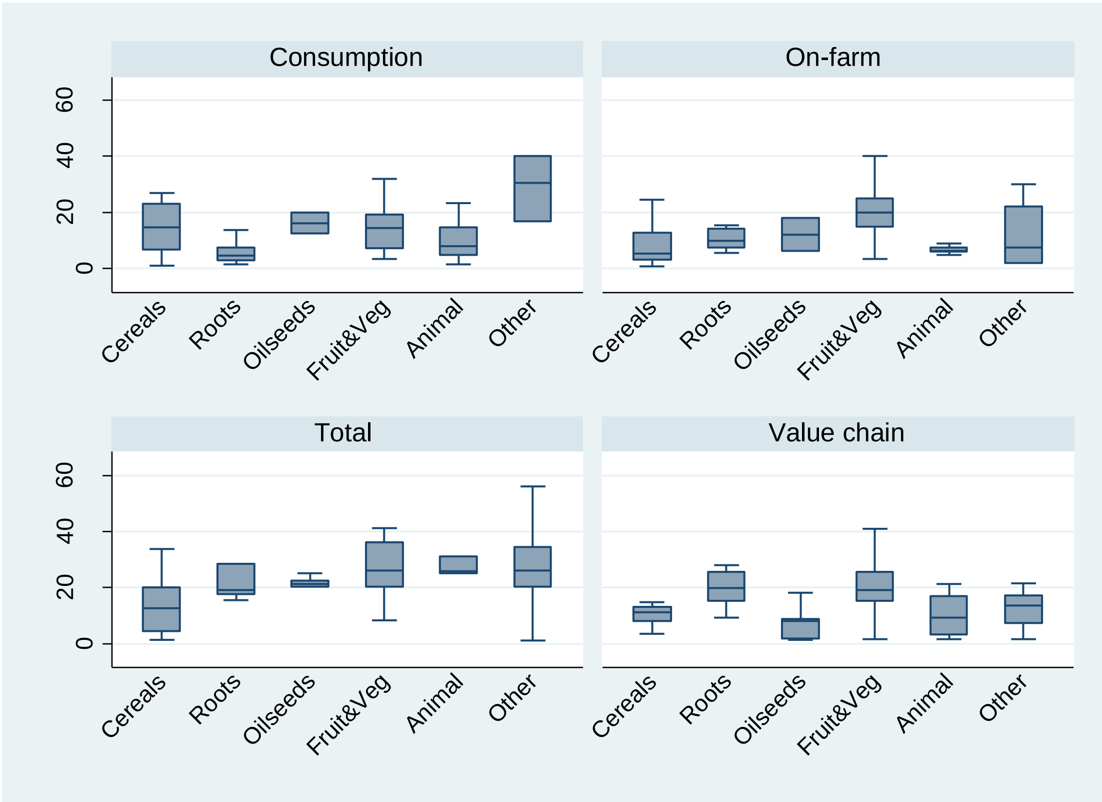
Figure 3a. Average losses by type of loss and commodity



Source: Author's calculations using various sources.

The distribution of losses shown in Figure 3b reflect the large losses in fruits and vegetables. Cereals also report a fairly large range of losses for consumption and on-farm, though median values are considerably lower for cereals on-farm than they are for other crops. The highest median was observed for fruits and vegetables across nearly all other types of losses.

Figure 3b. Box plots of postharvest losses by type of loss and commodity



Source: Author's calculations using various sources.

Describing the losses by type of loss, region and commodity offers insights into the difference across these categories. But do these categories explain the variation in the PHL estimates? If so, by how much? A simple analysis of variance (ANOVA) revealed that just by controlling for the type of loss, crops and regions approximately 20 percent of the variance is explained. The ANOVA revealed that while type of losses and commodity show significant differences between group variability, regions do not.

Infrastructural variables

The main principle guiding the selection of choice variables was the importance these variables play in explaining not only PHL but also economic development in a broader sense as discussed in previous sections.

Below we outline the infrastructure and governance variables selected, the reason for selecting them and the expected direction of the coefficients in the regression analysis. All variables were obtained from the World Bank, via its World Development Indicators interface. Table 3 presents the selected variables.

Table 3. Selected infrastructural variables and rationale

Variable	Rationale	Expected direction
Electric power consumption (kWh per capita)	Access to technology	Reduce PHL directly
Port infrastructure	Access to markets by sea	Reduce PHL indirectly
Air transport, freight (million ton-km)	Access to markets by air	Reduce PHL indirectly
Road density (km of road per 100 sq. km of land area)	Ability to transport goods	Reduce PHL directly
Roads, goods transported (million ton-km)	Intensity of transport capability	Reduce PHL directly
Roads, paved (% of total roads)	Quality of transport capability	Reduce PHL directly
Railways, goods transported (million ton-km)	Access to markets by train	Reduce PHL indirectly
Mobile cellular subscriptions (per 100 people)	Modern access to information	Reduce PHL indirectly
Telephone lines (per 100 people)	Access to information	Ambiguous
Government stability	Provision of an enabling environment	Reduce PHL indirectly
Rural population density	Rural markets	Reduce PHL indirectly

Source: WB WDI 2013

Unit cost data to estimate required levels of investments were drawn from a variety of sources. For road infrastructure (both development and maintenance), information was taken from the World Bank's Road Cost Knowledge System (ROCKS). Costs for electricity were obtained from US Energy Information Administration (http://www.eia.gov/). We also obtained costs of tons per kilometer of rail transportation. This information came from a technical report about the costing of railroads in Canada (DAMF et al. 2007).

Econometric specification and results

Three specifications are presented in Table 4 below. Specification number 1 regresses the transformed rate of PHL losses against infrastructural variables and the appropriate dummies. Number 2 adds a governance variable which accounts for the stability of government, which is a key indicator of governance.

Table 4. Econometric results

Variables	**(1)**	**(2)**
Dependent variable: proportion of PHL (between 0 and 1)		
Dummy for port quality (1=high, 0=low)	1.250	1.250
	(0.403)	(0.403)
Electric power consumption (kWh per capita)	0.688**	0.688**
	(0.110)	(0.110)
Air transport, freight (million ton-km)	1.073	1.073
	(0.0516)	(0.0516)
Road density (km of road per 100 sq. km of land area)	1.121	1.121
	(0.148)	(0.148)
Roads, goods transported (million ton-km)	0.876**	0.876**
	(0.0485)	(0.0485)
Roads, paved (% of total roads)	0.573**	0.573**
	(0.145)	(0.145)
Railways, goods transported (million ton-km)	0.921***	0.921***
	(0.0262)	(0.0262)
Mobile cellular subscriptions (per 100 people)	0.941	0.941
	(0.0914)	(0.0914)
Telephone lines (per 100 people)	2.288***	2.288***
	(0.512)	(0.512)
Port capacity*	1.327**	1.327**
	(0.151)	(0.151)
Government stability	1.377	1.377
	(0.410)	(0.410)
Rural population density	1.384	1.384
	(0.418)	(0.418)
Dummy for roots	2.994***	2.994***
	(0.869)	(0.869)
Dummy for oilseeds	2.549**	2.549**
	(0.979)	(0.979)
Dummy for fruits and vegetables	1.426	1.426
	(0.315)	(0.315)
Dummy for animal	0.862	0.862
	(0.321)	(0.321)
Dummy for other	1.904**	1.904**
	(0.480)	(0.480)
Dummy for on-farm losses	1.125	1.125
	(0.359)	(0.359)
Dummy for total losses	2.088**	2.088**
	(0.227)	(0.221)
Dummy for value chain losses	0.546*	0.546*
	(0.168)	(0.168)

Variables	(1)	(2)
Dummy for Asia	0.535	0.535
	(0.203)	(0.203)
Dummy for LAC	0.935	0.935
	(0.511)	(0.511)
Dummy for MENA	0.292**	0.292**
	(0.156)	(0.156)
Dummy for developed countries	0.142***	0.142***
	(0.104)	(0.104)
Constant	0.0216	0.0216
	(0.0537)	(0.0537)
Observations	208	208
R-squared	0.452	0.452

Notes:
*Container port traffic (TEU: 20 foot equivalent units).
Standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Right-hand side variables were regressed in their natural log form when appropriate. This was done to reduce issues of non-linearity, heteroskedasticity and other minor deviations from normality. Since the natural log is a monotonic transformation, the scaling in the data has been preserved.

The coefficients of the results presented in Table 4 are expressed in odds ratios, meaning that coefficients measure the impact of changes in the right hand-side variables on the ratio of PHL over the rate of no PHL (see method section). Thus, coefficients greater than one increase the odds of PHL, while coefficients less than one decrease it.

The results provide support to the importance of roads, particularly paved roads, which reduce the odds of PHL by half. Higher usage of railroads expressed by the amount of goods transported, which also measures to some degree the intensity of market transactions, also helps decrease PHL. Higher consumption of electricity also helps decrease the odds of PHL, perhaps signaling that more consumption leads to increased use of technologies that require power. Not all infrastructural coefficients showed the expected signs. Higher capacity of ports seems to increase the odds of PHL, perhaps reflecting significant issues related to the transportation of good to ports, particularly in developing countries. Similarly, increased numbers of landlines per 100 people also seem to increase PHL. We would have expected availability of cell phones to be an important factor in decreasing PHL, as it has been shown to play an important role in speeding up development in general (Aker and Mibiti 2010)

No significant effects were found for the governance variable.

Dummy variables indicating the region, crop and type of loss all report results that are in line with the descriptive section. For instance, roots and oilseeds increase the odds of PHL relative to cereals. At the same time, regional dummies for developed countries and MENA show that these regions are less likely than Africa to incur in PHL.

Based on these estimated coefficients and the unit costs of we estimated the infrastructure investments costs for achieving PHL reductions. The results include simulations for various levels of decreases in PHL. Table 5 illustrates the required investments in four types of infrastructure for a 5 percent decrease in PHL.

Table 5. Investment (US$) requirements in infrastructure to reduce PHL by 5 percent

Region	Electricity[a]	Paved Roads[b]	Rail Capacity[c]	Road Capacity[d]
Africa	10,493,751,296	7,027,633,152	57,907,712	6,256,584,192
Asia	80,715,096,064	209,079,418,880	35,974,656,000	403,101,483,008
LAC	32,002,551,808	14,760,436,736	3,956,525,824	22,900,320,256

Notes:

[a] Investments for electricity are for a 69 percent increase in per capita consumption. An average of coal and natural gas source was used as basis

[b] Investments for paved roads are for a 45 percent increase in maintenance and construction (average costs of the two) of paved roads.

[c] Rail capacity refers to investments required to increase the millions of tons per kilometer capacity of goods transported by rail by 98 percent

[d] Road capacity refers to investments required to increase the millions of tons per kilometer capacity of goods transported by road by 95 percent

Estimates derived from global regression. Estimates for MENA not available due to lack of enough observations to calculate marginal effects.

We do not have a unit cost for millions of tons per km as we do for rail. Cost for road maintenance was used instead.

The estimation of the investments costs for PHL scenarios described in Table 2 are based on the results shown Table 5. For Scenario 1, we assumed that the 10 percent decrease in PHL would be generated with 2.5 percent in PHL reduction from each of the investment categories presented in Table 5, resulting in a total investment of US$ 415 billion. The estimated regression coefficients for the investment impacts are conditioned on the underlying values of all of the investments in the data set, so a balanced increase in infrastructure is the most plausible approach. For Scenario 2, we assumed that reducing PHL in developed countries would be less expensive in terms of infrastructure investment given that the physical infrastructure is already in place and therefore most of the effort in the developed countries has to focus on behavioral changes. The recognition of the challenges behind changing behavior has led us to add 25 percent of the developing country investments to achieve the same percentage reductions in developed countries. This results in a global total of US$ 515 billion in investments under Scenario 2. Scenario 3 considers the overall PHL reduction as an average of the individual losses for the three commodity categories detailed in section 4. This has translated into an overall investment that is 16.8 percent higher than scenario 1, or US$ 485 billion. Using the Scenario 3 as a basis and considering the average losses described for Scenario 3, we added 25 percent to account for the investments in developed countries, for a total investment of US$ 605 billion in Scenario 4.

IFPRI IMPACT Model Results

The decrease in PHL represented stylistically in IMPACT as increases in effective yields leads in almost all cases in lower commodity prices by 2050. The price decreases are in the 10-20 percent range with only a few exceptions. Processed oil observe price decreases but on the range of 2-4 percent, which reflects the important role of capital and labor, and the fact that oilseeds like soybeans are only one input into the processing activity. Unsurprisingly, world prices decrease more in the scenarios where the PHL assumptions were applied globally (PL2 vs PL1, and PL4 vs PL3). The effects of expanding PHL reduction to developed countries contributes an additional 4-5 percentage points to the projected price declines observed under PL1 and PL3.

Under the scenario of increased investment in agricultural research, price reductions for crops are larger than for PHL reduction scenarios, with prices for most crops declining by more than 20 percent in 2050 relative to the baseline. The livestock price effects are not as great as for crops, because of the lower projected yield enhancements for livestock compared to crops (see Table 2), but are nevertheless comparable to the first PHL scenario (PL1).

As already mentioned above the changes in prices can have profound effects on both consumer and producer behavior. The decreases in agricultural commodity prices seen in Table 6 are significant in leading to the increased availability of affordable food globally. Tables 7 and 8 summarize the projected effects that these lower prices would have on food security regionally and globally by 2050.

Table 6. World prices in 2050 (% change from baseline)

Commodity	**PL1**	**PL2**	**PL3**	**PL4**	**AR1**
Beef	-11.5	-15.1	-15.3	-19.6	-11.0
Lamb	-13.9	-16.6	-19.2	-22.5	-11.3
Pork	-9.3	-14.9	-12.2	-19.2	-10.9
Poultry	-11.8	-17.0	-14.9	-21.1	-13.0
Dairy	-6.9	-9.8	-9.3	-13.0	-7.0
Eggs	-13.8	-17.2	-18.2	-22.1	-12.8
Rice	-19.8	-21.6	-10.8	-12.1	-26.3
Wheat	-12.5	-16.6	-7.2	-8.9	-20.4
Maize	-0.0	-2.7	0.8	-0.8	-3.0
Groundnuts	-18.5	-21.0	-10.7	-12.2	-25.5
Rapeseed	-8.4	-15.4	-5.1	-8.3	-19.3
Soybeans	-11.4	-16.9	-5.9	-8.6	-21.0
Fruits and Vegetables	-14.0	-16.9	-19.7	-23.2	-20.7
Pulses	-14.5	-17.4	-8.3	-9.9	-21.5
Roots and Tubers	-14.3	-16.2	-7.3	-8.6	-20.1
Processed Oils	-3.4	-4.1	-2.1	-2.9	-4.7
Oil meals	0.1	1.7	1.0	3.6	0.4

Source: IFPRI IMPACT Model version 3 (2014)

Table 7. Population at risk of hunger in 2050

Region	million						% change from baseline				
	BSL	**PL1**	**PL2**	**PL3**	**PL4**	**AR1**	**PL1**	**PL2**	**PL3**	**PL4**	**AR1**
East Asia and Pacific	126	118	116	120	119	115	-6.3	-7.5	-4.6	-5.7	-8.6
Europe and Central Asia	38	37	37	37	37	37	-2.9	-3.7	-2.4	-3.2	-4.1
LAC	48	45	44	46	45	44	-6.0	-7.7	-4.7	-6.2	-8.6
MENA	38	37	36	37	37	36	-3.9	-4.9	-2.8	-3.4	-5.8
South Asia	162	138	134	144	141	131	-15.3	-17.6	-11.5	-13.5	-19.2
SS Africa	137	116	112	120	118	108	-15.8	-18.6	-12.3	-14.3	-21.2
Developing	509	452	442	465	457	434	-11.2	-13.1	-8.5	-10.1	-14.7
Developed	59	56	55	57	56	55	-4.7	-6.1	-3.7	-4.9	-6.9
World	568	508	497	522	514	489	-10.5	-12.4	-8.0	-9.5	-13.9

Source: IFPRI IMPACT Model version 3 (2014)

Table 8. Number of malnourished children in 2050

Region	million						% change from baseline				
	BSL	**PL1**	**PL2**	**PL3**	**PL4**	**AR1**	**PL1**	**PL2**	**PL3**	**PL4**	**AR1**
East Asia and Pacific	8.3	7.9	7.8	8.0	8.0	8	-4.1	-4.9	-2.8	-3.4	-6.0
Europe and Central Asia	1.6	1.5	1.5	1.5	1.5	1	-4.9	-6.6	-3.9	-5.0	-7.6
LAC	2.0	1.8	1.7	1.8	1.7	2	-10.1	-13.5	-8.5	-11.5	-14.8
MENA	2.0	1.8	1.7	1.8	1.8	2	-8.9	-11.6	-6.9	-8.7	-13.8
South Asia	52.6	51.3	50.9	51.7	51.5	51	-2.5	-3.2	-1.7	-2.1	-3.8
SS Africa	36.8	35.1	34.7	35.7	35.4	34	-4.7	-5.7	-3.1	-3.8	-6.9
Developing	103.0	99.2	98.3	100.4	99.8	97	-3.7	-4.6	-2.6	-3.2	-5.5
Developed	0.2	0.2	0.2	0.2	0.2	0	-2.2	-3.0	-1.9	-2.5	-3.4
World	103.2	99.4	98.5	100.6	100.0	98	-3.7	-4.6	-2.6	-3.2	-5.5

Source: IFPRI IMPACT Model version 3 (2014)

Increased food availability due to these scenarios are projected to significantly improve food security, as shown in the tables. For developing countries as a group, the population at risk of hunger is projected to decline by 9-15 percent relative to the baseline in 2050. Malnourished children decline by 2-5 percent. Under both of these metrics AR1 followed by the PL2 scenarios show the largest declines in food insecurity with a decline of over 70 million at risk of hunger (Table 7), and around 5 million children (Table 8). Both of these metrics are closely tied to changes in per capita calorie consumption, which explains why PL2 shows the largest effects among the PHL scenarios, as this scenario has the largest reduction in losses of high calorie grains like rice and wheat. The regions where most of the biggest improvements in food security are observed are South Asia and Sub-Saharan Africa.

Reductions in commodity prices under these scenarios has a straightforward effect on consumers, where this serves as a relative increase in income, as they are able to purchase a more food with the same resources. Most farmers globally are net consumers of food and would benefit from lower prices. Nevertheless, prices decline can have a negative effect for producers if they are not compensated by increased productivity. To determine if the price declines are beneficial to society as a whole, we do a welfare analysis and quantify the benefits and losses accrued by different segments of society. This is done by estimating the producer and consumer surplus and net welfare changes induced by each scenario compared to the baseline. The following tables will highlight the results of this welfare analysis under alternative discount rates. The discount rates used in this analysis are:

1. Medium discount rate 5 percent
2. High discount rate 10 percent
3. Low discount rate 3 percent

The global results of the welfare analysis using a discount rate of 5 percent can be seen in Table 9, which shows the percentage changes and economic returns relative to the baseline. The economic value of the percentage changes in consumer surpluses are estimated with respect to projected total world agriculture gross production value through 2050, starting from the 2010 value of US$ 2.3 trillion (FAOSTAT database, accessed on December 18, 2014). The projected lower food prices have a negative effect on producers in all five scenarios because lower prices are only partially offset due to increased productivity. The losses for all scenarios are in the range of US$ 2,000-3,000 billion, ranging between 3.7-5 percent declines in producer surpluses, with the largest declines occurring in the global scenarios (PL2 and PL4) where we see the largest price declines among PHL scenarios. Although producers are losing, consumers are benefitting, and the benefits accruing to consumers is larger than the losses observed for producers. This difference is both true in terms of magnitude (gains are US$ 4,100-6,100 billion), and in terms of percentage gains. Subsequently, society as a whole benefits, as the benefits received by consumers can compensate for the losses observed by producers. Total welfare is projected to increase by 3 percent to over 4 percent compared to the baseline. As was observed for prices effects, the additional gains from expanding the PHL investments to developed countries has a smaller relative effect (0.8 and 1.0 percentage points for PL2 and PL4 respectively) on welfare change than the effects on welfare from improvements in just the developing world (3.1 and 3.4 percent for PL1 and PL3 respectively). One potentially counterintuitive result is that the agricultural research scenario shows the smallest change despite having the largest price changes by 2050. This result is due to the larger upfront gains in the PL1-PL4 scenarios, compared to the smaller but growing benefits through 2050 in AG1 (Table 9).

Table 9. Global change in producer surplus, consumer surplus and welfare by 2050 between baseline and investment scenarios, using a discount rate of 5 percent

	US$ billion change from baseline					**% change from baseline**				
	PL1	**PL2**	**PL3**	**PL4**	**AR1**	**PL1**	**PL2**	**PL3**	**PL4**	**AR1**
Producer Surplus	-2,288	-2,867	-2,526	-3,133	-2,043	-3.7	-4.7	-4.1	-5.1	-3.3
Consumer Surplus	4,508	5,796	5,060	6,440	4,140	4.9	6.3	5.5	7.0	4.5
Welfare	2,220	2,929	2,534	3,307	2,097	3.1	3.9	3.4	4.4	2.8

Source: IFPRI IMPACT Model version 3 (2014)

Table 10 summarizes the results across alternative discount rates. The welfare analysis under the high discount rate scenario shows a decline in the welfare benefits accrued from the investment in the five scenarios. Welfare still increases globally, but the changes in producer surplus, consumer surplus, and welfare are less than one-third of those observed in the medium discount rate scenario. Under the low discount rate scenario the gains in total welfare are about 75 percent higher than those observed in the medium discount rate scenario. Developing countries get more than 80 percent of the total global welfare gains in all scenarios.

Table 10. Change in producer surplus, consumer surplus, and welfare by 2050 under different discount rates

	US$ billion		
	5 percent discount rate	**High-discount rate scenario (10 percent)**	**Low-discount rate scenario (3 percent)**
PL1			
Producer Surplus Change	-2,288	-653	-4,020
Consumer Surplus Change	4,508	1,277	7,944
Welfare Change	2,220	624	3,924
PL2			
Producer Surplus Change	-2,867	-821	-5,031
Consumer Surplus Change	5,796	1,646	10,204
Welfare Change	2,929	825	5,173
PL3			
Producer Surplus Change	-2,526	-712	-4,456
Consumer Surplus Change	5,060	1,416	8,948
Welfare Change	2,534	704	4,492
PL4			
Producer Surplus Change	-3,133	-885	-5,520
Consumer Surplus Change	6,440	1,806	11,379
Welfare Change	3,307	921	5,859
AR1			
Producer Surplus Change	-2,043	-550	-3,691
Consumer Surplus Change	4,140	1,101	7,516
Welfare Change	2,097	551	3,825

Source: IFPRI IMPACT Model version 3 (2014)

Benefit-Cost Analysis

Each of the scenarios is driven by increased investment, with total infrastructure and research investment costs summarized above. In addition to assessing the economic rates of return to PHL reductions under the full investment costs, the rates of return are examined at lower cost allocations. The rates of return to investment for infrastructure and technologies that would lead to PHL reductions would likely have large benefits in other sectors of the economy, as expansion of roads, electricity, and railways benefit the economy more broadly beyond the agricultural sector, whereas the scenario focusing on agricultural research investments targets primarily this sector, and would have relatively small spill-over effects on other sectors of the economy. Therefore infrastructure investment cost allocations to PHL reduction of 50 percent and 25 percent are also assessed for the PHL scenarios. Table 11 summarizes the distribution of incremental investment costs over time cost for each of the scenarios as the increased investments are phased in.

Table 11. Investment scenarios

Scenario	**Years**	**Annual Investment/Cost Allocation Scenarios (US$ billion per year)**		
		100 percent	**50 percent**	**25 percent**
PL1	From 2014 to 2029	27.67	13.84	6.92
PL2	From 2014 to 2029	34.33	17.17	8.58
PL3	From 2014 to 2029	32.33	16.17	8.08
PL4	From 2014 to 2029	40.33	20.17	10.08
AR1	From 2014 to 2025	Starts at 0.67 growing to 8	NA	NA
	From 2026 to 2050	Held constant at 8		

Source: Authors

Table 12 summarizes the benefit-cost analysis for each of the five scenarios under the three discount rate scenarios, with 100 percent attribution of the PHL investment costs to PHL reduction. All of the scenarios generate benefits that are substantially higher than investment costs. The PHL scenarios have benefit-cost ratios (BCR) ranging from 6 to 15, depending on the discount rate assumption. At any given discount rate, there is very little difference in BCR across the four PHL scenarios, as scenarios with higher benefits are also characterized by higher costs. The importance of the growing benefit streams generated by productivity growth and lower costs of investment under the agricultural research (AR1) scenario are clear. The BCR for the AR1 scenario is more than twice to more than three times higher than for the PHL scenarios, depending on the discount rate.

Table 12. Benefit-cost analysis under 100 percent cost allocation

	Discount Rate	PL1	PL2	PL3	PL4	AR1
Benefits derived from investments (US$ billion)	3 percent	3,924	5,173	4,492	5,889	3,825
	5 percent	2,220	2,929	2,534	3,304	2,097
	10 percent	624	825	704	921	551
Costs (US$ billion)	3 percent	274	343	320	400	109
	5 percent	203	254	237	296	66
	10 percent	110	126	118	147	22
BCR	3 percent	14	15	14	15	35
	5 percent	11	12	11	11	32
	10 percent	6	7	6	6	20

Source: IFPRI IMPACT Model version 3 (2014)

Even when the BCR for the PHL scenarios doubles when only 50 percent of the costs of infrastructure development are allocated to PHL reduction, the BCR for AR1 remains substantially higher than the BCR for the PHL scenarios. The BCR for the PHL scenarios become greater than the AR1 agricultural research investment scenario only under the 25 percent cost allocation for PHL.

Conclusions

In this work we have provided a comprehensive review of the state of PHL in various regions of the world as well as across types of losses and commodities. Moreover, we have conducted econometric work to link losses with infrastructural and governance variables. The premise of our work is that infrastructure is of primary importance to explaining PHL as well as to providing the enabling conditions for adoption of PHL-reducing technologies.

Our literature review discussed a number of issues pertaining to PHL. First, it highlighted the reasons for the renewed interest in reduction in PHL as a contributor to improved food security, particularly after the 2008-2011 hikes in food prices. Second, it showed that estimates of losses vary dramatically across studies and types of losses. The measurement of losses is also found to be problematic by a number of papers. To derive better estimates of the potential benefits from the reduction of PHL, the conditions for improvement in PHL, and the appropriate policies and investments, it is critical to develop better measurements of loss along the value chain for key commodities. Third, the impact of PHL on food security has not been clearly established in the literature. While a number of studies point to the financial costs from PHL, the magnitude of the costs associated with remedying losses is also estimated to be high in many cases. Fourth, we have reviewed the existing literature that assesses the gains from adopting selected technologies and found that PHL technologies can lead to significant reduction in losses if properly applied, but may in some require a scale of production that excludes smallholders. Of critical importance, poor infrastructure is a barrier to PHL reduction, and adoption of PHL-reducing technologies is facilitated by the development of improved infrastructure.

Based on the findings of the review, we conducted empirical analysis to seek to explain levels and potential reductions in PHL due to infrastructural variables. To do so, we applied a weighted grouped logistic approach in order to ensure that fitted values of losses remain within the range of 0-1. Results point to the important roles of electricity, roads, particularly paved roads, and railways in reducing PHL. Dummy variables also revealed significant difference across commodities and regions. For instance, roots and tubers, oilseeds and fruits all increase the probability of higher of PHL relative to cereals. At the same time, regional dummies indicate that relative to Africa the probability of PHL is lower for all other regions. Infrastructure development is an essential enabling condition for achieving lower PHL.

Next, we utilized the estimates of impact of infrastructure on PHL together with the unit costs of infrastructure development to estimate a number of scenarios for the investment costs required to reduce PHL. These investment scenarios were then implemented in the IMPACT global food supply and demand model to simulate the impacts of reductions in postharvest food losses on food prices, food security measures, producer and consumer surpluses, net welfare gains, and benefit cost rations to the investments. These scenarios show that investment in infrastructure for PHL reduction contributes to lower food prices, higher food availability, and improved food security, and has positive economic rates of return. However, comparison with a scenario of increased investments in agricultural research shows that improvements in food security and BCRs and marginal returns to investment in agricultural research are considerably higher for investment in agricultural research than for investment in PHL reduction. Reductions in PHL are not a low-cost alternative to productivity growth for achieving food security. Rather, large-scale reduction in PHL requires large public investments and is complementary to investments in long-term productivity growth to achieve food security.

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Appendix

Appendix Table 1. Description of specific technologies

Types of Technologies	Commodity	Brief Description	Sources
ON-FARM			
Curing	Roots; Tubers; Bulbs	• Important for a month storage • Reduces water loss and decay rates • Keep the produce in high temperature and high relative humidity such as ambient field conditions for several days to allow harvesting wounds to heal and form new protective layer • Number of curing days depends on the produce - Onions and other bulbs: 1 day or less at 35^{o}C and 60-75% relative humidity - Yams, other tropical root and tuber crops can be left for about 4 days - Sweetpotatoes = 1,000 lb at capital costs of US$ 325, market value at US$ 15/40-lb carton	Kitinoja and Gorny 1999
Drying	Rice; Other grains	• Exposure of produce to the sun or other heating device to lower the moisture content and avoid build-up of contaminants (pests, fungi) in the produce • Traditional method of solar-drying on the farm bed or national roads for grains (e.g. rice in the Philippines, Indonesia, Cambodia, Myanmar, and Lao PDR) • Flat-bed dryer, 1-2 ton capacity – appropriate technology shifting from traditional drying to mechanized system	
Cooling		• Simple, low-cost hydro portable cooler – precooling (rapid cooling) of produce immediately after harvest to remove field heat for optimal keeping quality; consists of GI pipes lined with woven bamboo slats and plastic sheets; water added and cooled using ice • Low-cost on-farm cool storage – zero energy cool chamber (ZECC); example is the walk-along cool storage of 1,000kg mixed vegetables harvest during hot season in India	ZECC: Kitinoja 2010

Types of Technologies	Commodity	Brief Description	Sources
Milling	Rice	• Village-level, single milling machine, 40-300 kg/hour capacity - One-stage milling machine - consists of steel huller that accommodates husking and polishing; milling recovery is 50-55% which is extremely low, head rice recovery less than 30% - Two-stage milling machine - more sophisticated; with husker usually in the form of rubber roller and steel polisher; milling recovery above 60%	
Use of shade	Vegetables	• Locally constructed in the farm and can be used for several years; example on vegetable harvest at 200 kg in Cape Verde	Kitinoja 2010
Packaging		• Field packing done during selection, sorting, trimming and packing the produce while still in the farm • Minimizes mechanical damage by reducing the number of postharvest handling steps from the farm until it reaches the consumer • Cheaper or reduced cost since there is no need to build and manage a packinghouse and minimal handling issues - Use of small, mobile field packing station – designed to move along with packers and to provide shade during packing operations - Example: 1,000 lbs table grapes harvested and field packed by 4 trained workers (picked trimmed, packed at 25 lbs/carton, and $S0_2$ pads inserted) in 2 hours; losses calculated to be 10% vs typical 20% losses associated with grading, trimming, packing and cooling grapes in a local packinghouse; workers at field packing paid at $1.00 more per hour than field laborers who harvest crops to be transported to the packinghouse • Use of improved containers for handling and transport of fresh produce - Use of smaller sacks for 1,000 kg harvest in Ghana - Large sacks (70 kg produce/sack) - Smaller sack (35 kg minimum/sack)	Packing station: Kitinoja and Gorny 1999 Improved containers: Kitinoja 2010
VALUE CHAIN			
Drying	Rice	• Circular bamboo mats popular in Vietnam - Made up of bamboo bin, additional central duct, small axial-flow blower, and electric heater or coal furnace - Dried less than 2% of the mechanically dried rough rice	

Types of Technologies	Commodity	Brief Description	Sources
		- Cost: US $100 per unit • Mechanical dryers for higher head rice yield - Western-type re-circulating batch dryers or continuous flow dryer – used for export-quality rice - Locally produced or imported re-circulating batch dryer, 6-10 ton capacity - Simple locally-produced flat-bed dryer, 4-10 ton capacity	
Packing		• Modified atmosphere packaging – use of polymeric films or commercial plastic films such as low-density polyethylene, high-density PE, polypropylene bags to reduce weight loss, wilting and delay in fruit ripening and general deterioration of fruits and vegetables during transport and storage	
Storage	Rice; Wheat; Maize; Other Grains; Cocoa	• Non-hermetic storage - Zero Fly bags, less than 100 kg capacity – use of insecticide infused polypropylene bags provided a powerful killing action against insects, limiting infestation of the grain within the bag; short period where insects were able to survive before contact with inner lining of bag; cost: US$ ≤$3.50 per bag - Traditional granaries, 1,000+ kg capacity - improvement to traditional storage; made of local material and inexpensive to construct; rodent protected but unable to resolve pest infestation, moisture control and resistance to the elements; cost: to be determined • Hermetic storage encloses grains in airtight container to minimize gas (oxygen) and moisture movement from ambient air, and thus protects the grain from water adsorption, pests, and fungi; pilot testing and evaluation of this system (commercial level and smaller trials) in Asia, Africa, and Latin America demonstrated that this storage system maintains moisture content, controls insect, rodents, other pests and pathogens effectively, seed germination rate above 90% even after 9-12 months of storage, and less broken grain in milling with higher head rice recovery of between 2-10% in a 9-month storage - Oil drum, 200-liter capacity = US$ 2-5 - Locally constructed systems depend on purchase price of recycled	Metal silo: Fischler et al. 2011

Types of Technologies	Commodity	Brief Description	Sources
		containers or clay pots - Storage bags, 50 kg capacity, recyclable – cost: US$ 0.5-1 - Super Grain bags, less than 100 kg capacity – multi-layer polyethylene storage bags placed inside ordinary storage bags for additional layer of protection; cost: US$ 2.5-3 - Plastic silos, 100-150 kg capacity - plastic PVC storage units; cost: US$ 20-36 - Metal silos, 100-3,000 kg capacity - cylindrical structure from galvanized iron sheet; cost: US$ 35-375; example of using metal silo for storage by Central American farmer - Large commercial systems – cost: US$ 50-100 per ton with expected life cycle of at least 10 years	
Cooling system	Tomato; Chili; Cabbage; Chinese Kale; Chinese Mustard; Aromatic Mustard	• Simple evaporative coolers - cool and humid conditions to delay the quality deterioration of vegetables such as d; reduce weight loss by 50-80% compared to ordinary room storage - Brick-walled cooling system – double-walled made of clay brick where containers are fitted neatly inside with 10-20 cm space filled with sand as insulator and jute sack covering the wooden frame moist with water - Box type evaporative cooling systems – made of wooden slats and covered with tight fitting jute sack moist with water	
Milling		• Commercial mills - Small-scale, 0.5-2 tons/hr capacity - employs specialized machines for cleaning, husking, polishing, grading and bagging in multistage process; milling and head rice recoveries are 3% and 10% respectively higher than village milling in Cambodia - Large-scale, 2-6 tons/hr up to maximum of 100 tons/hr capacity - with additional equipment such as de-stoners, mist polishers, color sorter added to the milling lines; some with dryers; milling recovery is 65-68% and head rice recovery is 50-55%	

Appendix Table 2. Sources of postharvest data

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Appendix Table 3. List of regional aggregates and country groupings

1. *Developed countries*
   1.1. Europe including Russia
   1.2. North America & Oceania
   1.3. Australia
   1.4. Canada
   1.5. UK
   1.6. USA

2. *Africa*
   2.1. Sub-Saharan Africa
   2.2. East & Southern Africa
   2.3. Ghana
   2.4. Kenya
   2.5. Malawi
   2.6. Sudan
   2.7. Tanzania
   2.8. West Africa
   2.9. Zambia

3. *Asia*
   3.1. South & Southeast Asia
   3.2. Industrialized Asia
   3.3. Bangladesh
   3.4. China
   3.5. India
   3.6. Indonesia
   3.7. Korea
   3.8. Malaysia
   3.9. Nepal
   3.10. Pakistan
   3.11. Philippines
   3.12. Thailand
   3.13. Singapore
   3.14. Sri Lanka
   3.15. Vietnam

4. *Latin America*
   4.1. Brazil
   4.2. Bolivia
   4.3. Venezuela

5. *Middle East*
   5.1. Egypt
   5.2. Iran

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