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World Poverty and the Role of Agricultural Technology: Direct and Indirect Effects

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Agricultural technology can help reduce poverty through direct and indirect effects. Direct effects are gains for the adopters while indirect effects are gains derived from adoption by others leading to lower food prices, employment creation, and growth linkage effects. Conceptualizing and measuring these effects is highly complex, yet is needed for each region if technology is to be used as an effective instrument for poverty reduction. We propose a methodology for doing this in the context of computable general equilibrium modeling and apply it to archetype models for Africa, Asia, and Latin America. Results show that the dominant effect of technology on poverty is through direct effects in Africa, indirect agricultural employment effects in Asia, and linkage effects through the rest of the economy in Latin America. In each case, increasing the poverty reduction effect through the targeting of technology across crops and through complementary rural development programs is also explored.

I. Direct and indirect effects

As demonstrated by the experience of the Green Revolution, which led to a doubling or tripling of yields for the major foodgrains in the 1960s and 70s, technological change in agriculture can be a powerful force in reducing poverty. In their review of the social benefits of the Green Revolution, Lipton and Longhurst (1989) enthusiastically concluded that: "Indeed, if social scientists had in 1950 designed a blueprint for a pro-poor agricultural innovation, they would have wanted something very much like the Modern Varieties: labor-intensive, risk-reducing, and productive of cheaper, coarser varieties of food staples". The way this aggregate result came about was, however, a complex phenomenon, and there were not only gainers among the poor. While, overall, the largest poverty reduction effect is likely to have been on consumers through falling prices for staple foods (Pinstrup-Andersen, 1979), there were other benefits for the poor through adoption by smallholders, employment creation for the rural landless, and growth linkage effects with the non-farm economy (Hazell and Ramasamy, 1991). There were also losers among the poor. Small farmers were sometimes displaced by large farmers, tenants by owners, workers by labor-saving innovations, and producers in marginal areas by those in better endowed environments (Scobie and Posada, 1978). Hence, using the technology instrument as part of a strategy for poverty reduction requires careful ex-ante analysis of how the nature of technology, the nature of poverty, and the economic and institutional context in the particular region where technology is released affect the distribution of benefits and losses. Typically, a set of interventions complementary to the release of technology is also needed to maximize beneficial social effects, particularly in areas of extensive poverty with weak market, institutional, public goods, and policy support to potential adopters. Implementing these complementary interventions requires coordination between those who develop the technology and the other development agents in the region who can provide these interventions if they are needed for technology to have impact on poverty. The current re-orientation of the CGIAR (Consultative Group on International Agricultural Research) toward a regional approach seeks precisely to achieve greater impact on poverty through this coordination (CGIAR, 2000).

There are two channels through which technological change in agriculture can act on poverty.[2] First, it can help reduce poverty directly by raising the welfare of poor farmers who adopt the technological

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[2] We define poverty as "being poor", namely having insufficient income (including production for home consumption) to meet a poverty line defined as a consumption threshold. We prefer to leave the many other dimensions that determine welfare outside the poverty concept. Hence, for us, "underdevelopment is

innovation. Potential benefits for them can derive from increased production for home consumption, higher gross revenues from sales and lower production costs.

Second, technological change can help reduce poverty indirectly through the effects which adoption, by both poor and non-poor farmers, can have on the real income of others through:

The price of food for consumers.

Employment and wage effects in agriculture.

Employment, wage, and income effects in other sectors of economic activity through production, consumption, and savings linkages with agriculture, lower costs of agricultural raw materials, lower nominal wages for employers (as a consequence of lower food prices), and foreign exchange contributions of agriculture to overall economic growth (Adelman, 1975; Haggblade, Hammer, and Hazell, 1991).

Through the price of food, indirect effects can benefit a broad spectrum of the national poor, including landless farm workers, net food-buying smallholders, non-agricultural rural poor, and the urban poor for whom food represents a large share of total expenditures. Indirect effects via employment creation are important for landless farm workers, net labor-selling smallholders, and the rural non-agricultural and urban poor. Hence, the indirect effects of technological change can be very important for poverty reduction not only among urban households, but also in the rural sector among the landless and many of the landed poor.

There has been an active debate among development economists about the relative importance of the direct and indirect effects of technological change in reducing aggregate poverty in a particular region. The problem emerges if the technological innovations (choice of crops and bias of technological change) used to achieve these two effects are not the same, implying trade-offs in the allocation of public research budgets between these two effects, or biases in the impact of privately released technologies on these two effects. In a cautionary note, Byerlee (2000) argues that capturing these trade-offs in sufficient detail is beyond our capacity at the current level of knowledge, and that research should consequently focus on the major food staples without attempting any detailed poverty targeting. To him, more important is to be concerned with the overall efficiency of research systems rather than with a better focus on poverty. In a similar perspective, Alston, Norton, and Pardey (1995) argue that the main benefit of agricultural technology is through greater food availability and a lower price of food. According to them, research should consequently focus on generating the greatest aggregate output gain, while concerns for poverty reduction among smallholders should be achieved through other instruments. This will generally suggest focusing on farmers with the most land and on the better endowed areas. This is in stark contrast to those who argue that, in an era of excess world food supplies, the role of technology in reducing poverty should be sought through direct effects. Altieri (1998) thus recommends that the CGIAR should focus its attention on resource-poor farmers located in marginal lands which have been largely bypassed by agricultural research. Fan and Hazell (2000) similarly argue for the case of India that marginal returns to research investments are higher in less favored areas where research investments have been minimal compared to irrigated lands where past research investments have depressed marginal returns.

When are there trade-offs between direct and indirect effects? Within a given agro-ecological environment, if land is unequally distributed and if there are market failures, institutional gaps, and conditions of access to public goods that vary with farm size, then optimum farming systems (crops and technologies) will differ across farms. Small farmers will typically prefer farming systems that are more labor intensive and less risky, while large farmers would prefer farming systems that are more intensive in capital and they can afford to assume risks in exchange for higher expected returns. In this case, unless land is unimodally distributed (e.g., in countries like Burkina Faso or Taiwan with generalized smallholder agriculture), heterogeneity of farming systems prevails and there are typically trade-offs between achieving indirect and direct effects with a given research budget. The more unequally land is distributed and the more market failures, institutional gaps, and public goods deficits are farm size specific, the sharper the trade-off.

Note that the degree of tradability of commodities benefiting from technological change is key in determining the relative importance of direct and indirect effects (see for example the multimarket analysis for India by Quizon and Binswanger, 1986, and the computable general equilibrium (CGE) analysis for

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multidimensional", but not poverty, as opposed to the WDR 2000/2001 (World Bank, 2000) and the IFAD Rural Poverty Report 2000/2001 (IFAD, 2000) according to which "poverty is multidimensional".

Bolivia by de Franco and Godoy, 1993). For non-tradable commodities, falling prices can extract from adopting farmers most of the net social gains from technological change to the benefit of rural and urban consumers, as for example in the case of potatoes in Bolivia studied by de Franco and Godoy (1993). However, even in an open economy where the price of food is internationally determined, indirect effects can be important through the multiple roles of agriculture in economic development. Using a fix-price multiplier model, Delgado, Hazell, Hopkins, and Kelly, 1994, and Delgado, Hopkins, and Kelly, 1998, show that the magnitude of the linkage effects of technological change in the agricultural tradable sector depends on the degree of tradability in the rest of the economy. Hence, once an economy is open and goods are internationally traded with low transactions costs, technological change in high value crops may produce larger indirect effects than technological change in the production of staple foods that can be acquired cheaply on the international market. What matters, in this case, is to carefully identify the role of agriculture as a source of aggregate income growth (Winters, de Janvry, Sadoulet, and Stamoulis, 1998) and how aggregate income growth translates into poverty reduction by mechanisms that will generally be other than through the price of food.

II. Differential incidence of direct and indirect effects across poor households

As world population is becoming increasingly urbanized, the role of technological change in reducing aggregate poverty correspondingly evolves from direct to indirect effects. Yet, it is striking that the share of rural in total poverty remains so high. As the data in Table 1 show, for the countries with available information, rural poverty accounts on average for 68% of total poverty, reaching 93% in populous countries such as Bangladesh and 76% in India. This is in part due to the fact that the incidence of rural poverty is much higher than the incidence of urban poverty. On average across countries in Table 1, the incidence of rural poverty is 17 percentage points higher than that of urban poverty. It is only in some of the Latin American countries that the urban poor are a majority (e.g., 78% in Brazil, 76% in Paraguay, and 65% in Peru), stressing the inevitably dominant role of indirect effects in these countries. In the rest of the developing world, and in many of the Latin American countries as well, the rural sector remains the main reservoir of poverty. Data on extreme poverty would accentuate the relative importance of the rural sector in total poverty even more. Reducing rural poverty should expectedly require both direct and indirect effects. The question which we need to address is how much of rural poverty can be attacked via direct versus indirect effects. We turn for this to a characterization of the sources of income for the rural poor.

In his extensive survey of non-farm incomes for rural households in developing countries, Reardon (1998) reviews case studies for 18 African, 14 Asian, and 5 Latin American countries. He defines non-farm income as income generated from non-agricultural activities (non-agricultural wage and self-employment income), excluding income from agricultural wage and other sources of income such as transfers. For most of the case studies reviewed, non-farm income represents on average between 25% and 40% of rural income. Data on sources of income reported in Table 2 focus on subgroups of poor rural households. It shows that, even for poor farm households, off-farm incomes (which include agricultural wage income) are a very important source of total household income, averaging 55% in the countries listed in Table 2. In Nicaragua, households on the 45% smallest farms derive 61% of their income off-farm. In Mexico, in the ejido sector, households on the 57% smallest farms derive 76% of their income off-farm. In Chile, the 60% poorest farm households derive 67% of their income from off-farm activities. Off-farm incomes are even more important among poor rural households than among poor farm households. As examples, the 60% poorest rural households derive 80% of their income from off-farm activities in El Salvador and 86% in Ecuador. The poorest 50% derive 68% of their income from off-farm activities in Panama and 50% in Pakistan. The average for countries listed in Table 2 is 68%. Hence, indirect effects have to be very important for the rural poor, including the landed poor. Observing extensive levels of poverty among smallholders should thus not automatically be taken to imply that using technology to achieve direct poverty reduction effects is the most effective approach to poverty reduction among them.

Among off-farm sources of income, agricultural wage employment tends to be important for poor rural households, both landless and landed, particularly where land is highly unequally distributed as in Latin America and where there is a lot of landlessness as in South Asia. Among rural households, the poorest 60% derive 45% of their total income from agricultural wage labor in El Salvador and 54% in Ecuador (Table 2). Hence, for technological change in agriculture to be poverty reducing, employment creation has to be a key feature. Technological change that is labor-saving (e.g., mechanization and herbicides) is likely to have adverse effects on rural poverty (The Nuffield Foundation, 1999).

Finally, in weighting the relative roles of direct and indirect effects in poverty reduction, we need look at the consumption side as well. Many smallholders are net buyers of food. Hence, they will benefit from indirect effects through lower food prices created by technological change in the fields of other producers, small and large. A number of other smallholders are self-sufficient, and hence unaffected by the fall in price that may be induced by the diffusion of technological change. For them, technological change will create direct effects through higher efficiency in producing their food needs. Data for Nicaragua (Davis et al., 1998), Mexico (de Janvry, Gordillo, and Sadoulet, 1997), and Southeastern Senegal (Goetz, 1992) reported in Table 3 show the distribution of households among net buyers, self-sufficient, and net sellers. As net buyers, 23% (Nicaragua) to 37% (Senegal) of the farm households in these countries will benefit from indirect effects of technological change through the price of grains. Direct effects benefit self-sufficient and net-selling households that represent 53% (Senegal) to 69% (Nicaragua) of the total number of farm households.

In addition to the direct profit effect and the indirect agricultural employment and food price effects, all households will potentially be affected by the macro-economic effects that a sufficiently important technological change in agriculture can induce. These macroeconomic effects include growth and employment effects due to linkages between agriculture and non-agriculture, and real exchange rate effects that can result from changes in imports or exports. How much poor households are affected by the real exchange rate effect depends on the tradability of the consumption goods that they consume. We will see later that these effects, which could not be captured in partial equilibrium analyses, can be large, justifying a general equilibrium approach.

III. Measuring the relative importance of direct and indirect effects

Quantifying the relative magnitudes of the direct and indirect poverty reduction effects of technological change is quite difficult as these effects are interrelated and depend on the nature of the technological change, the structure of poverty, and the policy and institutional context where technology is released. Because general equilibrium effects are involved, we use a CGE approach for archetype economies representing poor countries in Sub-Saharan Africa, Asia, and Latin America (Sadoulet and de Janvry, 1992).[3] These archetype economies are not designed to represent an entire region or to be a sample of countries in the region, but rather to characterize a set of common structural characteristics to countries in the region.[4]

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[3] de Franco and Godoy also use a CGE, while other studies of the indirect effect of agricultural technology have used multimarket models (Quizon and Binswanger, 1986) or semi-input-output models (Haggblade, Hammer, and Hazell; 1991, Delgado at al., 1994 and 1998). Multimarket models have a detailed formalization of the agricultural sector with substitution across crops and between inputs, allowing for a good characterization of technology. Yet, they take the non-agricultural sector as exogenous and ignore the macro-economic equilibrium, and hence cannot properly account for linkages outside the agricultural sector, nor for real exchange rate effects. Semi-input-output models are small fixed-price Keynesian-type multiplier models. They consider both agricultural and non-agricultural sectors, but split them into pure tradable and pure non-tradable sub-sectors, with non-tradables assumed to have an infinitely elastic supply. These models cannot capture price effects. The endogenous-price model used by Haggblade, Hammer, and Hazell (1991) allows for a less than infinite elasticity of supply of the non-tradable sector, therfore allowing for an increase in the price of non-tradables.

[4] The archetypes were built on the basis of aggregate information for a set of low income food importing countries in the three continents, and social structure coming from Social Accounting Matrices from Kenya for the Africa archetype, Sri Lanka for the Asia archetype, and Ecuador for the Latin America archetype. The Africa archetype uses aggregate information from the following countries: Benin, Burkina Faso, Central African Republic, Ethiopia, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Mali, Mauritania, Mozambique, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Tanzania, Togo, and Zaire. The Asia archetype uses information from Bangladesh, Sri Lanka, Pakistan, Philippines, Papa New Guinea, China, and India. The Latin America archetype uses information from Brazil, Chile, Colombia, Costa Rica,

CGE models are homogenous of degree one in all prices and nominal values. Hence, they can only solve for relative prices and not for an absolute level of prices. This requires that a numéraire be chosen. Note that the choice of numéraire does not affect any real value obtained from the simulation, in particular the real income effect of technology, but it does affect the allocation between direct and indirect effects. Technological change in agriculture is expected to induce a decline in agricultural prices relative to non-agricultural prices, in particular because of the increased demand for other domestically produced goods due to income effects. If, at one extreme, the numéraire is an index of non-agricultural prices, then the relative price change is read as a decline in the agricultural price, leading to important positive indirect effects on real incomes and probably very low or even negative direct profit effects in the agricultural sector. If, on the other hand, the numéraire is close to the agricultural prices, relative price changes are read as an increase in non-agricultural prices, leading to high direct effects and negative indirect effects. To seek a more neutral choice, we use as numéraire the nominal exchange rate, so that all results can be read in dollar terms, and the decomposition of effects that we report in the tables reflects changing prices relative to the dollar price of the commodities.

A second issue with respect to the division between direct and indirect effects is the allocation of self-employment on farm and homegrown consumption of food to these effects. Although the level of on-farm self-employment of family labor responds to the external wage when the labor market works, we will consider it as part of the direct effect of technological change on farm income. Regarding home consumption, assume for a moment that the household is self-sufficient in food, so that production and consumption of the agricultural product are equal. Then, a decrease in the agricultural price, which in fact does not affect the welfare of the household, appears as a negative direct effect on agricultural profit and a positive indirect effect from the decline in the consumer price. To avoid this artificial accounting, we impute the change in value of the initial home consumption of own production to the direct effect. Hence, only the decline in the value of what is sold by net sellers is counted as a direct loss and only the decline in price of what is purchased by net buyers is counted as an indirect price effect.

In summary, we measure household welfare W by real income, which is nominal income y divided by a household idiosyncratic consumer price P. The nominal income of a given household can be divided into profit income in agriculture and other income (see Appendix 1):

$$W = \frac{y}{P} \text{ and } y = (p_a^q q_a - x_a) + y_{-a},$$

where p_a^q, q_a, x_a and y_{-a} are the producer price, the production level, the production costs in agriculture, and the non-agricultural income of the household, respectively. The three components of the welfare effect of technological change reported below are:

- Direct effect: $\left(p_a^q q_a - x_a\right) - \left(p_a^{qo} q_a^o - x_a^o\right) - \left(p_a^q - p_a^{qo}\right)\min(c_a^o, q_a^o) + (wL - w^o L^o)$
- Indirect income effect: $y_{-a} - y_{-a}^o - (wL - w^o L^o)$
- Indirect price effect: $y\left(1 - \frac{P^o}{P}\right) + \left(p_a^q - p_a^{qo}\right)\min(c_a^o, q_a^o)$,

where $c_a, w,$ and L are consumption of agricultural product, wage, and on farm self-employment, respectively, and the superscript ^{o} refers to the value of variables before the technological change. The direct effect includes the change in agricultural profit, the changing opportunity cost of home consumption of own production, and the change in self-employment on own farm. The indirect income effect comes from the change in nominal income from all sources other than self-employment in own agricultural production. The indirect price effect comes from the change in prices, excluding the effect through the opportunity cost of home consumption.

IV. Features of the social accounting matrices (SAM) and the CGE models

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Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, and Paraguay.

In Table 4, we present the main features of the archetype economies.[5] The three archetypes have similar aggregation schemes. The sectoral aggregation includes three agricultural sectors (export crops, cereals, and other agriculture), food processing, industry, trade-and-services, and administration in the African and Asian archetypes; and two agricultural sectors (export crops and other agriculture), minerals, industry, trade-and-services, and administration in the Latin American archetype. The labor disaggregation has been specified to reflect some regional differences. Africa and Asia each have three categories of labor: public employees, and a division of the remaining workers by residence (urban, rural) in Asia, and by skill in Africa. In Latin America, labor markets are relatively more integrated, with a categorization of workers by skill only. The definition of social classes is adapted to the individual contexts. While in Africa rural households are classified in three farm sizes, Asia has a large class of rural landless and two farm sizes, and Latin America has three farm sizes. The other accounts are similar in all three SAMS (firms, government, private and public capital accounts, and the rest of the world).

As we do not have information on intra-class income distribution, we cannot count the number of poor in each class. We sometimes refer to rural poverty as including the two poorest rural classes in all three economies, i.e., small and medium farm sizes in Africa, and landless and small farm size in Asia and Latin America. Similarly, we define urban poverty as including the low-education urban population in the three archetypes. Note, however, that social classes do not exactly correspond to poverty levels, as there are landless and small farm households that are not poor. The aggregates of these classes may be larger than the shares of the poor in these economies. The size of the groups that are defined as poor are thus not comparable from one archetype to another, since they are largely dependent on the aggregation scheme. Stricto sensu, our analysis examines the impacts of technological change on the socio-economic classes defined above, rather than on the poor. However, comparisons across experiments and across archetypes are interesting and indicative of how the poor will be affected by technological change.

The Sub-Saharan African economies are remarkable for the large share of agriculture in GDP (47%), and hence the large potential aggregate growth effects derived from technological change in agriculture. The shares of the three sectors in agricultural value-added are 28% for the export crops, 45% for cereals, and 27% for other agriculture that includes mainly non-tradable livestock. The share of rural households in total household income is high (61%). For the rural poor, income derived from agriculture is 67% of total income, with the remaining 32% derived from wage earnings. For them, agricultural commodities are a large share (72%) of total consumption.

The agricultural sector is smaller in Asia than in Africa, and even smaller in Latin America where it only accounts for 13.6% of GDP. The size of the diversified "other agriculture" sector also increases drastically from the African to the Asian and the Latin American archetype. The share of labor in agricultural value-added is not comparable between the archetypes. Because the casual labor market is very shallow in Africa, family labor has been included as a fixed factor and its contribution accounted for in profit income. By contrast, since labor markets in Asia and Latin America are active, family labor contribution is valued at its opportunity cost on the labor market and accounted for separately. Note that in our classification of poor and non-poor, as it is in the actual statistics on poverty level, poverty is largely urban in Latin America, as opposed to what is seen in Asia and Africa. Another important contrast between these economies is the importance of income diversification for rural households with on farm income (including family labor) decreasing from 67% in Africa to 25.6% in Asia, and to a low 16.4% in Latin America.[6] This immediately indicates that direct effects have a substantially lower potential in Asia and Latin America than in Africa. Finally, while in Africa the rural poor spend 72% of their budget on agricultural commodities, this share declines to 40.2% and 13.7% in Asia and Latin America, respectively. This is partly due to the higher income level (in Latin America) and to the relative importance of product transformation and hence consumption of goods from the food processing sector rather than directly from agriculture. Note that in Africa, all consumption of agricultural commodity is home produced[7], while in

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[5] The full Social Accounting Matrices for the three regions are posted in Appendix 2 of the paper on the authors' websites at the following addresses:
http://are.Berkeley.EDU/~alain/ and http://are.Berkeley.EDU/~sadoulet/.

[6] These shares do not include income for agricultural wage earned, and are therefore lower than the shares of farm (agricultural) income reported by Readon (1998) and cited above.

[7] More precisely the consumption of agricultural products is lower than the production for each of the classes included in the rural poor. This does not preclude heterogeneity within classes.

Asia, with a large class of landless, the poor only produce 67.3% of their consumption of agricultural commodities, and in Latin America they produce 83.6%. Hence, the rural poor of Africa are not affected by changes in the consumer food price.

The model used in this paper is a standard neoclassical CGE in which agents respond to relative prices as a result of profit maximizing and utility maximizing behavior in determining levels of production and consumption, and markets reconcile endogenous supply and demand decisions with adjustments in relative prices.[8] CGE models differ primarily in the choices of closure rules which equilibrate commodity, factor, and foreign exchange markets, in rules specified to reconcile the government budget constraint, and in the mechanism used to equilibrate savings and investment levels in the economy.[9] In our model, all commodity markets follow the neoclassical market-clearing price system, in which jointly determined producer and consumer prices vary only by given tax rates. Labor markets have been specified to reflect some regional differences. Africa and Asia each have three categories of labor: public employees, and a division of the remaining workers by residence (urban, rural) in Asia, and by skill in Africa. The two nonpublic categories of labor are imperfect substitutes. We assume that urban labor in Asia and skilled labor in Africa are in surplus and are thus hired at an exogenous real wage (in terms of the consumer price index). Wages for rural labor in Asia and unskilled labor in Africa are, in contrast, flexible. Public employees receive an exogenous, fixed real wage. In Latin America, labor markets are relatively more integrated, with a categorization of workers by skill only.

The foreign exchange market equilibrates via adjustments of the real exchange rate. With foreign borrowing fixed, and the additional constraint of a fixed balance of payments, the balance of trade is pre-specified at a constant level. Pressures to change export or import quantities (and hence, demand and supply of foreign currency) are therefore equilibrated by adjustments in the real exchange rate.

Government earnings comprise revenues raised from indirect taxes, trade taxes, and net foreign borrowing. Public outlays consist of non-targeted food subsidies, current expenditures on the services provided by the public sector, investment, and some small transfers to households and firms. Government transfers, current expenditures and investment expenditures are fixed. Government deficit is covered by borrowing on the domestic credit market.

Private investment is savings driven. Savings are generated by exogenous constant rates for households and by residual savings from firms. Private savings is equal to net savings available after government borrowing is covered.

The relationship between the rest of the world and the domestic economy is determined, for each sector, by the substitutability between imported and domestic goods on the consumption side, and by the substitutability in production for the domestic market and for the international market. The corresponding elasticities for the agricultural sectors are reported in Table 4. While the export crops sector in Africa is highly tradable, the other two are not due to the specificity of these crops. By contrast, cereals in Asia are almost perfectly tradable, which means that their price is essentially determined by the world price and the exchange rate, and not influenced much by domestic production. In Latin America, both agricultural sectors have a medium level of tradability. Note that imperfect substitutability with foreign commodities is largely an aggregation effect due to the fact that each sector is a composite of many commodities, some like rice and wheat identical to the internationally traded commodities, and others almost non-tradable at all. Allocations of demand and supply between the domestic and international markets occur in response to the relative prices of foreign goods, themselves defined by international prices, the exchange rate, and government policies (taxes, subsidies, and tariffs).

Real incomes are computed with social group-specific consumer price indices. The model solves for a one-period equilibrium and results have to be interpreted in comparative statics terms.

Our model is different from a standard CGE in the production specification for the agricultural sectors. A joint production function is specified for the agricultural sectors following the profit function approach used in multi-market modeling. This approach characterizes the nature of agricultural production at the farm level, in which combinations of crops produced and factors employed are jointly chosen as part

[8] The complete CGE model used is posted in Appendix 3 of the paper on the authors' websites at the following addresses:
http://are.Berkeley.EDU/~alain/ and http://are.Berkeley.EDU/~sadoulet/.

[9] A complete description of the model, with a list of all equations and values of all parameters, is available on the authors' web site.

of a single income strategy and where a variety of common fixed factors affects the levels of all activities. Nonagricultural sectors, in contrast, are represented by traditional multi-level CES production functions for primary factors and by fixed coefficient functions for intermediate inputs.

V. Simulation of alternative technological change

Table 5 reports the impact of different scenarios of technological change simulated in the African archetype. A 10% increase in total factor productivity due to technological change such as improved seeds in all crops creates income gains for both urban and rural households. Overall the rural poor households enjoy an increase of 7.6% in their real income, mostly from direct effects, and the urban poor an increase of 4.3%, from indirect income generation effects. These real income gains can be traced to general equilibrium effects as follows. Because agriculture is a large sector in African economies, the 10% increase in agriculture induces a large positive growth in non-agricultural employment (8.3%) and in real GDP (6.8%) that benefit both the rural and urban poor in terms of indirect income effects, although the urban more than the rural. This overall growth induces demand for food, mostly non-tradable, and hence weakens the decline in food price to only 6%. Growth also induces an increase in demand in other commodities that puts pressure on domestic prices and on imports. The result is almost no change in the real exchange rate despite the increase in agricultural exports. This leaves the urban consumer price index at its initial level (in dollar terms), in part because non-food prices increase and in part because most of the food consumed in urban areas comes from the food processing sector which has a large non-agricultural input content. Rural poor households produce all of the food they consume and hence do not benefit from a decline in food crop prices, and lose slightly from an increase in the price of what they purchase. Therefore, for rural households, the share of income gains that comes from direct effects is 77.1%, with almost half of the direct effect derived from home consumption of production. This unbalanced outcome between direct and indirect effects derives from the peasant structure of the agricultural sector. Technological change in agriculture is thus very effective for the rural poor, mainly through direct effects.

Targeting technological change on food crops, which have low tradability in Africa, creates a sharper decline in price (-12%). This decline in price is transmitted to the rest of the economy through lower wages, inducing a small depreciation of the real exchange rate by 3.5%. The net effect of these effects is a decline in the consumer price index that benefits consumers at large (a result that is similar to that found by de Franco and Godoy for technological change in the non-tradable potato sector).[10] At the same time, since the cereals sector is a small 13% of the economy, the aggregate effect on GDP is only 2.9% growth. As a result, the urban poor benefit essentially from indirect effects created by lower food prices and not by general growth effects. Income gains for the rural poor are almost exclusively captured through benefits in home consumption, since the drastic decline in the price of food crops negatively affects their marketed surplus. The negative price effect on rural income is even sharper when technological change is focused on livestock due to the larger marketable surplus in that sector with low tradability. In this case, it is the urban poor that benefit most, with a real income increase of 1.5% compared to the 0.5% increase for rural poor.

Finally, we can target technological change on either small or large (or all) farmers through complementary rural development interventions. The next three columns of Table 5 look at a 10% increase in land productivity due to land-saving technological change in seeds and agrochemicals. Targeting technical change on the land held by small and medium farmers gives rise to an aggregate growth effect of 2.6% compared with 3.4% with an untargeted technological change, since these farmers produce almost 75% of all agricultural value-added. However, for the small and medium farmers, targeting technological change on them raises direct effects and decreases indirect effects as prices decline less and employment effects are also less than if large farmers were involved. If, by contrast, technological change is captured only by the large farmers, direct effects on the rural poor are negative, as they face lower prices for their crops without having the beneficial effect of technology. Indirect effects are their only source of real income gains, and they are small. As a consequence, the urban poor are the main beneficiaries, with real income gains more than three times larger than those of the rural poor (0.7% vs. 0.2%). In Africa, rural development interventions to make poor farmers participate to technological change are thus important for

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[10] Recall that the price effect on home produced consumption is included in the direct effect, and not in the consumer price effect, explaining why the price effect is small for the small and medium farmers.

rural poverty reduction since indirect effects through large farmers' adoption never compensate for their loss of direct effects if they are excluded. These simulations for Africa illustrate the difficulty of using technology to reduce rural poverty. As rural poor farmers are largely specialized in the production of food crops for themselves and of non-tradable livestock for the market, any benefit from technological change in these activities will be lessened by falling prices. By contrast, the urban poor will benefit from falling prices of non-tradables and from employment creation when aggregate growth is sufficiently important.

A selected number of simulations with the Asian and Latin American archetypes are reported in Table 6 to illustrate contrasts brought about by differences in the structures of poverty and of the economies. An increase in land productivity in Asia produces a lower decline in food prices than in the other two regions, largely due to the greater tradability of the agricultural sectors. Agricultural imports sharply decline while agricultural exports increase, inducing an appreciation of the exchange rate. The food price decline is not sufficient to compensate for the increase in other prices induced by aggregate growth and real exchange rate appreciation, and hence the indirect price effect on the landless and the urban poor is negative. Self-sufficient small farmers are even more negatively affected by price increase since they do not benefit from the food price decline. Employment effects create strong income gains for all three groups, notably the landless class that benefits from agricultural employment growth. Note that even for the small farmers, the indirect effect is larger than the direct effect as profits on marketed surplus of agricultural production is largely tempered by the decline in price. Interestingly, it is the landless that benefit most from the technological change with an increase of 7.2% in real income compared to 6.2% and 5.0% for the urban poor and small farmers, respectively. In Asia, the employment effect of technological change is thus key in reducing poverty, even rural poverty. This labor demand effect of technology in reducing rural poverty in Asia had been observed by Otsuka (2000).

The same land productivity change in Latin America produces similar results on the individual classes. As the agricultural sector is smaller than in the other economies, one expects overall growth effect to be smaller. Yet, note that while the agricultural sector is only 14% of the aggregate GDP, rather than 32% in Asia, the overall growth of GDP is 3.8% compared to 5% in Asia. Hence each point of growth in agriculture has more linkage effects on the rest of the economy than in Asia. This is due to the fact that the agricultural sector uses more inputs and trade services than in the other economies. For all three classes, indirect income effects dominate the direct effect. All three classes are negatively affected by the increase in non-agricultural price that more than compensate for the food price decline. This happens despite a strong decline in consumer food prices because food consumption represents a smaller share of expenditures than in the poorer Asia. The main difference between the Latin American and the Asian cases is that the relative importance of the three targeted socioeconomic classes are quite different. The rural landless are few in Latin America, where poverty is mostly urban or among small farmers. Hence the linkage effects of technological change on the non-agricultural sectors are in Latin America key to the reduction of urban poverty.

Adoption of yield increasing technological change usually requires costly factor deepening. The second column of Table 6 illustrates for the Asian case a technological change akin to the Green Revolution, that is an increase in yield that is accompanied by a large increase in the use of chemical inputs. Based on yield and input use data for High Yielding Variety paddy compared to improved local varieties in South India (Hazell and Ramasamy, 1991), we simulated a 10% increase in land productivity accompanied by a 40% increase in the input coefficient for chemicals. The main result compared to column 1 is a tilting of the share of benefits toward non-agricultural activities and away from direct agricultural profit effects. This is seen in the fact that overall growth is lower (3.7% vs. 5%), but non-agricultural employment is larger (6.8% vs. 6.2%) and the total real income effect for the urban unskilled rises from 6.2% to 6.6%. Because of higher costs as adopters, small farmers achieve lower gains in their direct agricultural income from 5.0% to 3.4%.

The last two columns of Table 6 illustrate an interesting counterintuitive result whereby small farmers, overall in Latin America, could benefit more from a technological change targeted to medium and large farmers than if it were targeted to themselves.[11] This comes from the fact that: 1) the medium and

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[11] In all the simulations reported here, we assume 100% adoption rate in the crop or by the group that are targeted. However, comparing columns 4 and 6 of Table 5 shows the impact of the same land productivity technological change fully adopted by the non-poor farmers but adopted by 100% and 0% of the poor farmers, respectively.

large farmers represent a large class controlling more than 65% of agricultural production and 2) the small farmers depend for 65% of their income on off-farm labor employment. Hence, despite a larger increase in aggregate consumer price and a negative direct effect on the agricultural income of small farmers, the aggregate effect on small farmers is larger than if the technology had been targeted at their own land assets. For the urban poor too, employment effects largely compensate for the negative effect of the aggregate price increase.

There are important caveats to the results presented here. Continental contrasts are very blunt and can, at best, be used in support of broad reasoning about the relative role of direct and indirect effects in relating technology to poverty in highly stylized contexts. Each continent contains a large number of regions with different configurations of poverty, different production systems according to agroecological context and the land tenure system, and different economic and institutional structures. "African-type" situations, where rural poverty is dominated by smallholders, are found in Central America, the Andean plateau, and Northeast Brazil. In these regions of Latin America, aggregate poverty reduction may well call on focusing on direct effects. Hence, intra-continent heterogeneity calls on detailed regional analyses, where regions correspond to more homogenous conditions of poverty, agroecological regions (and hence technological options), and institutional-policy contexts. It is this regional analysis of poverty and the potential for technology to reduce poverty through direct and indirect effects that needs to be pursued through further analysis.

The second caveat is a reminder of the somewhat arbitrary decomposition between price and non-price effects. Computable general equilibrium model are real models, i.e., they express supply, demand and market equilibrium of real quantities of product and factors, and all prices are computed relative to a numéraire. Their results are thus unambiguous on quantities, on real income effects, and on relative price movements, which are independent of the choice of the numéraire. However, the decomposition of real income effects into nominal income and price effects depends on the numéraire chosen, and the decomposition of a relative decline of the agricultural price to the non-agricultural price or the foreign exchange as a decline in food prices or an increase in non-food prices is arbitrary. We have chosen to normalize the reporting of the results with the exchange rate. As a consequence, all nominal values are in dollar terms, and an appreciation of the real exchange rate is interpreted as an increase in domestic prices. Using an aggregate domestic price in lieu of the exchange rate as numéraire would have given less negative price effects (and corresponding nominal income effects) when there is appreciation of the exchange rate but, in all the Asian and Latin American cases reported in the simulations above, the consumer price effect would have remained negative.

Why is it therefore that an increase in agricultural production produces little benefits to consumers through a decline in the food price, at least in the simulations performed with our CGEs? Several factors interfere with this potential benefit. First, when food is relatively tradable as in the Asian case, an increase in production does not induce an important decline in food prices, although through decreased imports it creates an appreciation of the real exchange rate which has a broader effect on the price structure. This real exchange rate appreciation benefits the consumers of most tradable goods, not necessarily poor consumers. Second, even in countries where there is some decline in the price of agricultural goods (such as in Latin America and Africa where agriculture is less tradable), food consumed by the landless and urban poor is mostly processed and commercialized food (67% for the urban poor in Africa), and the share of agricultural products is a small fraction of the consumer cost of processed food (13% in Asia and 27% in Africa. In the Latin American case, the food processing sector is aggregated with the industrial sector which probably further dilutes the effect of a decline in the price of agricultural products for the urban poor.) In Latin America, the urban poor spend only 9% of their expenditures on non-processed food, while the corresponding share is 15.4% in poorer Africa. With such small shares in consumption, it is not surprising that any real exchange rate movement that produces an overall increase in the price of all other commodities overwhelmed the potential benefits of decreasing agricultural prices. As for the farmers, recall that the price effect on home produced goods is included in the direct effect and not in the consumer price effect. In the end, it is only when technological change is targeted on a mostly non-tradable sector of food production with limited linkage and aggregate growth effects (such as the cases of Africa reported in Table 4) that the food price decline is sufficient for inducing a positive effect on the real income of the urban poor.

This does not preclude that decreasing food prices are not important for some very poor households that spend a large share of their income on non-processed foods. But, at least at the level of aggregation that is considered in these models, this does not apply to the average household of any group.

It also does not contradict the presumption that a major factor in poverty reduction over the last decades has been the relative decline in food prices, but this usually refers to an effect of food production increase at a world scale. Such an overall growth in food production leaves most of the income and multiplier effects in the North, while the South benefits from the decline in food prices.

IV. Conclusion: role of technology in poverty reduction

We conclude by observing, first, that the relative role of the direct and indirect effects of technological change in reducing poverty depends on the nature of technological change, the structure of poverty, the structure of the economy, and the policy-institutional context where it is released. For this reason, deciding on which technology to choose, and how to accompany technology with complementary rural development interventions, to maximize poverty reduction must be carefully assessed for every particular context. Direct effects are important in reducing aggregate poverty in an economy that is as agrarian and rural as the African, but they are less so in Asia which has a large class of rural landless households, and even less in Latin America where the poor are overall largely urban and where even the rural poor have highly diversified sources of income with a high share of off-farm incomes. Second, results show that the targeting of technological change across crops and types of households can make a large difference on the effectiveness of technology in reducing poverty. To maximize direct income benefits, technological change needs to focus on small farmers' crops that are maximally tradable to avoid falling price effects. Contrary to the typical use of technological change in rural development, and if food markets work, this will often mean high value added export crops as opposed to food staples. Complementary interventions to target the benefits of technological change on smallholders are important to mitigate price declines and thus raise direct benefits to them. In Africa, designing technological change for small farmer production systems and assisting their diffusion among smallholders through rural development interventions are thus key to rural poverty reduction. By contrast, the urban poor will benefit from a decline in food prices when technological change is targeted to non-tradable food products. Note, however, that a broader technological change encompassing tradable agriculture as well, benefits the urban poor through the aggregate growth that it produces, even though the food price decline is lessened by the increased demand for food.

In the case of Latin America, indirect benefits derived from technological change come mostly from linkage effects through the rest of the economy. Even for poor farmers, technological change in the fields of large farmers can be more beneficial to them than the direct effects derived from a technological change targeted at their own farms. In this case, maximizing the aggregate productivity effects of technological change is the best approach to poverty reduction, both rural and urban, vindicating, at the level of social aggregation used in our models, the position advocated by Byerlee (2000) and by Alston, Norton, and Pardey (1995). Finally, designing technological change for maximum employment creation in agriculture is important for poverty reduction in Asia where the landless account for an important share of total poverty.

Technological change in agriculture can serve as an instrument for poverty reduction, but the distribution of these gains between direct and indirect effects, and hence across households in poverty, depends on each particular regional context. We found that the design of improved small farmer production systems, employment creation in agriculture, and aggregate productivity effects will be the dominant instruments for poverty reduction according to particular contexts. In each case, hence, the optimum balance between these three effects needs to be determined. The allocation of budgets to research, particularly when smallholder farming systems differ markedly from those of large farmers and when labor-saving technological options are available, needs to be adjusted to each particular regional situation. In addition, when complementary rural development interventions are needed to promote adoption by smallholders, those who develop the technology need to seek partnerships with the development agents in the region that can organize the rural development efforts. Otherwise, technological innovations will not produce the expected poverty reduction effects.

Analysis of the direct and indirect effects of technological change through an archetype CGE modeling approach shows how complex capturing these effects can be. Importantly, we have seen that the two most commonly cited effects of technological change, direct effects on farmers' agricultural incomes and indirect effects through a declining price of food for others, need not be the dominant effects. When poor rural households have diversified sources of income, including wage labor in agriculture or in non-agriculture, they may benefit from sustained growth in these other incomes more than from the direct impact of technology on their own farms. When the exports and imports of agriculture are sufficiently large, increased agricultural production will produce an appreciation of the real exchange rate of a significant order of magnitude, spreading the price effect over all tradables. Finally, when the income effect of technological change is large, linkages to the rest of the economy through final demand, also spread the benefits to a wide group of households with little apparent connection to agriculture. At the same time, it is evident that, to be practical for priority setting in using technology for poverty reduction, the analysis needs to be brought down to much finer eco-regional and geopolitical-regional scales. In addition, the analysis must evolve from model simulations to detailed empirical analyses of concrete achievements. There consequently remains a vast research agenda to be pursued to help make the role of agricultural technology in poverty reduction more cost effective for each particular regional setting.

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Table 1. Importance of rural poverty in total poverty in the 1990s

	Year	Rural Po %	Urban Po %	Total Po %	Rural population % of total	% of total poverty that is rural
Middle East						
Algeria	1995	30	15	23	51	68
Egypt	1996	23	23	23	50	51
Morocco	1999	27	12	19	46	66
Tunisia	1990	22	9	14	41	63
Yemen Rep	1992	19	19	19	83	84
South Asia and China						
Bangladesh	1995	40	14	36	84	93
India	1994	37	31	35	73	76
Mongolia	1995	33	39	36	41	37
Mongolia	1995	33	39	36	41	37
Nepal	1995	44	23	42	90	95
Pakistan	1991	37	28	34	67	73
Sri Lanka	1991	38	28	35	71	77
South-East Asia						
Cambodia	1994	43	25	39	78	86
Indonesia	1990	14	17	15	68	64
Lao PDR	1993	53	24	46	76	88
Philippines	1997	51	23	41	63	80
Thailand	1992	16	10	13	55	65
Vietnam	1993	57	26	51	80	90
Central Asia						
Kazakhstan	1992	46	29	42	74	82
Kyrgyz Rep	1997	65	29	51	61	78
Africa						
Cameroon	1984	32	44	40	37	30
Chad	1996	67	63	64	25	26
Ghana	1992	34	27	31	62	68
Guinea-Bissau	1991	61	24	49	67	84
Kenya	1992	46	29	42	74	82
Lesotho	1993	54	28	49	82	90
Madagascar	1994	77	47	70	77	84
Niger	1993	66	52	63	79	82
Nigeria	1992	36	30	34	62	66
Sierra Leone	1989	76	53	68	65	73
Zambia	1991	88	46	68	52	68
Zimbabwe	1991	31	10	26	74	90
Latin America						
Brazil	1990	33	13	17	22	41
Colombia	1992	31	8	18	42	74
Dom Rep	1992	30	11	21	51	74
Ecuador	1994	47	25	35	45	61
El Salvador	1992	56	43	48	41	48
Honduras	1993	51	57	53	67	64
Nicaragua	1993	76	32	50	42	63
Panama	1997	65	15	37	44	77
Paraguay	1991	29	20	22	24	31
Peru	1994	67	46	54	35	44
Trinidad & Tobago	1992	20	24	21	75	71
Simple average, all countries		45	28	38	56	68

Sources: World Bank, World Development Indicators; and CEPAL, Social Panorama, 1996
Poverty is defined as the population living below the national rural and urban poverty lines.

Table 2. Importance of off-farm income for the rural poor

Country	Percentage of households	% share of off-farm income in total household income	% share of ag. wage income in total household income	Source
Farm households				
Nicaragua	45% smallest farms	61		B. Davis et al. (1998)
Mexico (ejido)	57% smallest farms	76		de Janvry et al. (1997)
Panama	73% smallest farms	61		World Bank, LSMS (1998)
Chile	60% poorest	67		Lopez and Valdes (1997)
Paraguay	66% poorest	19		Lopez and Valdes (1997)
Pakistan	71% smallest farms	47		IFPRI Pakistan survey, 1986-89
Simple average		55		
Rural households				
El Salvador	60% poorest	80	45	Lopez and Valdes (1997)
Ecuador	60% poorest	86	54	ECV (1995)
Panama	50% poorest	68		World Bank, LSMS (1998)
Burkina Faso, Sahelian	All	57	2	Reardon et al. (1988)
Burkina Faso, Sudanian	All	65	26	Reardon et al. (1988)
Pakistan	50% poorest	50		IFPRI Pakistan survey, 1986-89
Simple average		68		

Table 3. Market participation of farm households in Nicaragua, Mexico, and Senegal.

Percentage of farm households	Corn Nicaragua	Beans Nicaragua	Corn Mexican ejido	Coarse grains SE Senegal
Net buyers	23	28	27	37
Self-sufficient	30	30	32	19
Net sellers	39	37	28	34
Sellers and buyers	9	5	13	10

Table 4. Characteristics of the regional archetypes

	Africa	Asia	Latin America
Share of agriculture in GDP	47.4	32.0	13.6
Sectoral shares in agriculture			
Export crops	28.0	24.9	33.2
Cereals	45.2	27.7	
Other ag.	26.8	47.4	66.8
Share of labor in ag.value-added	10.4	48.1	45.3
Substitutability domestic/foreign commodities			
Export crops[1]	1.2	1.2	0.8
Cereals[2]	0.3	30	
Other agriculture[2]	0.5	3.0	1.2
Household income shares			
Share of rural households in total household income	61.1	69.8	24.3
Share of urban households in total household income	38.9	30.2	75.7
Rural poor			
Share of on farm agricultural income in total household income	67.3	25.6	16.4
Share of off-farm labor income in total household income	31.6	41.4	63.2
Share of non-ag. self-employment and other income in total household income	1.1	33.0	20.4
Share of agricultural commodities in total consumption	71.9	40.2	13.7
Share of agricultural consumption produced at home	100.0	67.3	83.6
Urban poor			
Share of agricultural commodities in total expenditures	43.5	33.2	9.0

[1] Elasticity of substitution in CET export-domestic market allocation.

[2] Elasticity of substitution in CES import aggregate.

Table 5. Direct and indirect effects of technological changes on the real income of the poor, African archetype

	10% increase in total factor productivity			10% increase in land productivity		
	All crops	Food crops	Livestock	All farmers	Small and medium farmers	Large farmers
Aggregate effects (% change)						
Real GDP	6.8	2.9	2.0	3.4	2.6	0.9
Real exchange rate	0.6	3.5	2.5	0.4	0.1	0.3
Agricultural production	10.0	3.9	2.8	5.0	3.9	1.1
Non-agricultural employment	8.3	4.1	2.8	4.2	3.0	1.3
Consumer food crop price	-6.0	-12.0	-1.2	-3.3	-2.0	-1.3
Unskilled wage	-1.1	-3.4	-3.0	-0.7	-0.3	-0.4
Urban unskilled (% change in income)						
Direct effect	0.0	0.0	0.0	0.0	0.0	0.0
Indirect nominal income effect	4.3	-0.7	-0.7	2.3	1.8	0.5
Consumer price effect	0.0	2.4	2.2	0.1	-0.1	0.2
Total real income effect	4.3	1.7	1.5	2.4	1.7	0.7
Small and medium farmers (% change in income)						
Direct effect	5.8	2.8	-0.2	2.7	2.9	-0.1
Indirect nominal income effect	1.8	-0.1	-0.1	1.2	0.9	0.3
Consumer price effect	-0.1	1.2	0.8	-0.1	-0.1	0.0
Total real income effect	7.6	3.9	0.5	3.8	3.6	0.2
Share of direct effect (%)	77.1	72.0	-30.1	71.0	78.6	-67.4
Share of indirect effect (%)	22.9	28.0	130.1	29.0	21.4	167.4

Note: Direct effects include home consumption and self-employment on farm.

Table 6. Direct and indirect effects of technological changes on real income of the poor, Asian and Latin American archetypes

	Asia		Latin America		
	10% increase in land productivity		10% increase in land productivity of		
	With constant factor intensity	With 40% increase in chemicals intensity	All households	Small farmers	Medium and large farmers†
Aggregate effects (% change)					
Real GDP	5.0	3.7	3.8	0.5	2.7
Real exchange rate	-2.7	-2.1	-2.5	-0.3	-1.7
Agricultural production	8.8	8.7	8.0	1.0	5.5
Agricultural employment	7.4	7.2	4.7	0.6	3.2
Non-agricultural employment	6.2	6.8	5.3	0.7	3.7
Consumer cereal price	-1.5	-2.4	-7.0	-0.9	-4.9
Unskilled wage	1.5	0.7	2.2	0.3	1.5
Urban unskilled (% change in income)					
Direct effect	0.0	0.0	0.5	0.0	0.0
Indirect nominal income effect	8.0	7.7	7.1	0.9	5.0
Consumer price effect	-1.8	-1.1	-2.5	-0.3	-1.7
Total real income effect	6.2	6.6	5.1	0.6	3.4
Landless (% change in income)					
Direct effect	0.5	0.3	0.8	0.0	0.1
Indirect nominal income effect	7.8	7.3	6.8	0.9	4.8
Consumer price effect	-1.1	-0.4	-2.4	-0.3	-1.6
Total real income effect	7.2	7.2	5.3	0.6	3.3
Share of direct effect (%)	7.5	4.3	15.8	1.5	2.7
Share of indirect effect (%)	92.5	95.7	84.2	98.5	97.3
Small farmers (% change in income)					
Direct effect	2.2	0.4	1.1	1.8	-0.4
Indirect nominal income effect	5.2	5.0	6.2	-0.1	4.9
Consumer price effect	-2.4	-2.1	-3.0	-0.4	-2.1
Total real income effect	5.0	3.4	4.3	1.4	2.4
Share of direct effect (%)	43.6	12.8	26.4	129.4	-17.8
Share of indirect effect (%)	56.4	87.2	73.6	-29.4	117.8

Note: Direct effects include home consumption and self-employment on farm.
† Includes corporate farming.

Appendix 1
Evaluation of direct and indirect effects with CGE simulations

CGE models assume that markets exist and function for commodities. The equilibrium price is then established by equilibrium between supply and demand. For example, food produced and consumed at home is accounted for in both income (valued at the producer's price) and expenditures (valued at the consumers' price). Because trade margins are small on agricultural products, the difference between the two prices is not a major discrepancy.

Factors of production are assumed either to be fixed or variable. Fixed factors (such as land and capital) capture a rent computed as the residual profit, after profit maximizing producers have established the level of use of variable factors. Variable factors are paid at their equilibrium price established on a competitive market. Assumptions regarding the functioning of the labor market vary from one case to the other, depending on what fits best the economy. In the African CGE, family labor is assumed to be a fixed factor, based on the observation that casual labor markets are very thin. By contrast, in the Asian and Latin American CGEs, family labor are assumed to have the casual wage as opportunity cost. The consequence of these assumptions is that production is not responsive to changing wages in the African CGE, while it is in the other two archetypes. The possibility of using the labor market for employment of family labor or to hire extra workers also allows the agricultural sector in these two economies to be more responsive to changes in output prices. Using the dual formulation of supply function, rather than the primal formulation of production function, does not impose that production be solely increased through the use of variable factors. It can also increase by higher use of fixed factors.

In terms of the allocation of welfare effect into direct and indirect, both issues of consumption of own commodities and use of family labor raise some problems. Welfare is measured by real income, which is nominal income y divided by a household idiosyncratic consumer price P. Nominal income of a given household can be divided into profit income in agriculture and other income:

$$W = \frac{y}{P} \text{ and } y = (p_a^q q_a - x_a) + y_{-a},$$

where p_a^q, q_a, x_a and y_{-a} are the producer price, the production level, and the cost of agriculture, and the non agricultural income of the household, respectively. The consumer price level is a Laspeyres index based on the initial consumption structure. It can be written as:

$$P = p_a c_a^o + P_{-a}$$

where p_a and c_a^o are the consumer price and the initial consumption of agricultural commodities, and P_{-a} stands for the terms involving other consumer goods.

A change in welfare due to changes in prices and quantities is then decomposed as follows:

$$P^o \Delta W = y - y^o - y\left(1 - \frac{P^o}{P}\right) = \left(p_a^q q_a - x_a\right) - \left(p_a^{qo} q_a^o - x_a^o\right) + y_{-a} - y_{-a}^o - y\left(1 - \frac{P^o}{p_a c_a^o + P_{-a}}\right)$$

where the superscript ^{o} refers to value of variables before the changes. The first two terms represent the change in agricultural profit, which can be called the direct effect. The other terms represent the indirect effect with two components, an income effect that comes from changes in nominal income from all sources other than agricultural profit and a consumer price effect. Assume for a moment that the household is self-sufficient so that production and consumption of the agricultural product are equal, and additionally that it does not change, $q_a = q_a^o = c_a^o$. Then, a decrease in the agricultural price, which does not affect the welfare of the household, in fact appears as a negative direct effect on agricultural profit and a positive indirect effect from the decline in the consumer price. To avoid this artificial accounting, we impute the change in value of the initial home consumption to the direct effect as follows:

$$P^o \Delta W = \underbrace{\left(p_a^q q_a - x_a\right) - \left(p_a^{qo} q_a^o - x_a^o\right) - \left(p_a^q - p_a^{qo}\right)\min(c_a^o, q_a^o)}_{\text{direct effect}} + \underbrace{y_{-a} - y_{-a}^o}_{\text{indirect income effect}}$$
$$\underbrace{-y\left(1 - \frac{P^o}{P}\right) + \left(p_a^q - p_a^{qo}\right)\min(c_a^o, q_a^o)}_{\text{indirect price effect}}.$$

Hence, only the decline in the value of what is sold is counted as a direct loss and only the decline in price of what is purchased is counted as an indirect price effect.

The imputed income of family labor working on-farm is also included in the direct effect, and taken out of the indirect income effect. Hence, the three components of the welfare effect become:

- Direct effect: $\left(p_a^q q_a - x_a\right) - \left(p_a^{qo} q_a^o - x_a^o\right) - \left(p_a^q - p_a^{qo}\right)\min(c_a^o, q_a^o) + (wL - w^o L^o)$
- Indirect income effect: $y_{-a} - y_{-a}^o - (wL - w^o L^o)$
- Indirect price effect: $y\left(1 - \frac{P^o}{P}\right) + \left(p_a^q - p_a^{qo}\right)\min(c_a^o, q_a^o)$.