Part One

Technology's Contribution to Poverty Reduction?

Technology and Poverty: Mapping the Connections[1]

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What Relationship between Technology and Poverty Reduction?

On a long historical view, technological advance has been instrumental to rising living standards and, by inference, to poverty reduction across the globe. The world would be far poorer, were it not for the successive waves of innovation since the beginning of the Industrial Revolution in Europe. Maddison (2001) calculates that the rate of growth of world per capita GDP increased by a factor of 24 with the Industrial Revolution — from a mere 0.05 per cent per annum in 1000–1820 to 1.21 per cent a year from 1820 to the present. It may seem self–evident that the more than one billion people who still live in poverty remain largely excluded from technology's benefits, but this begs the question of how it can help to alleviate their poverty.

While the absolute numbers of poor people in the world continue to rise, poverty incidence has fallen in many countries — including some very large ones like the People's Republic of China (PRC) and India — over the past several decades. What role has technology played in this story? What are the potential benefits of emerging technologies — e.g. agricultural and medical biotechnology, information and communication technology — to the many remaining poor of the developing world? What features of the policy, institutional and legal environment are instrumental in directing more innovative effort into solving the problems of the poor and encouraging widespread uptake of promising new technologies by the poor?

Although, as this paper shows, technology has made an important difference for poverty reduction, it is not the only contributory factor. Institutional change, responding sometimes to technological change and sometimes to government policy or social pressures, has also been important. For instance, while technology has played a role in the PRC's dramatic reductions in rural poverty, so have institutional reforms in agriculture since 1978. Also, technology seldom works its effects in a vacuum; it is embedded in social systems and, whether adopted by individuals or organisations, it usually involves adjustments in accustomed practices. Behavioural and/or organisational change is normally a *sine qua non* for realising the full potential of a new technology[2].

In mapping the connections from technology to poverty, we do well to bear in mind the reverse connections as well, from poverty alleviation to enhanced human capability to use technology. Insofar as poverty reduction associates closely with improvements in human health and education, i.e. in the quality of human capital, it will likely improve the conditions for technology adoption and innovation. Lipton (2001) points to a virtuous circle, whereby technological advances in agriculture lead to improvements in health and human productivity, declining mortality and fertility rates, increased investment in children's education and enhanced human capabilities to develop and use new techniques. While a large empirical literature maps links from nutrition and health to worker productivity (cf. Craig *et al.*, 1997, and Strauss and Thomas, 1998, for a literature review), the links from poverty reduction to technical progress are less direct and more difficult to establish empirically. Not explored extensively here, this reverse causality could offer a promising avenue for future research.

For the very poor, many common technologies may not be available. Yet a catalogue of the technologies that poor people in rural areas of the developing world often do encounter in their everyday lives might include modern seed varieties and other inputs used to grow food; motors to power pumps, farm machinery, and vehicles to transport produce to market (where animal traction or human leg–power are no longer the main means); electricity; vaccines, antibiotics and other medicines; and radio and perhaps TV. Not all are advanced, state–of–the–art innovations fresh from the R&D laboratories of multinational corporations, leading universities or publicly funded research institutes (like the various agricultural research institutes that form the CGIAR network). Some are rather mundane technologies present for many generations in the developed world and, very often, considered obsolete there. Others have been developed to address local technical problems in specific developing countries and might be classed as "intermediate technologies". Whether they represent economically *valuable* technical advance depends on whether they make possible, in production, greater output (or better quality) with the same or fewer inputs or, in consumption, greater human satisfaction within given budget constraints. They represent economically *important* technologies largely when, singly or in combination, they contribute to lifting large numbers of people out of poverty.

In what follows, it proves convenient to distinguish among three sorts of technology, although the lines dividing them are not always clear:

— *Process* technologies that result in increased productive efficiency and/or improved product quality;

— *Product* technologies, i.e. new products with direct welfare benefits to consumers (medicines, artificial contraceptives, micronutrient–enhanced grains, etc.); and

— *Transaction* technologies that facilitate co–ordination, information sharing and exchanges between buyers and sellers or other sets of economic agents, reducing transaction costs.

This paper is concerned principally with two broad sets of technologies: agricultural innovations (beginning with the green revolution technologies and continuing with agricultural biotechnology) and information and communications technologies (beginning with the computer and continuing with mobile telephony and the internet). The former fits more neatly into the category of process technologies, although modern agricultural biotechnology also has a strong product–technology dimension, while the latter are both process technologies and — especially in the case of the internet and other communications media — transaction technologies.

One can approach the topic of technology and the poor from one of two perspectives, by asking "Where are the poor and how does technology affect their lives?" or, alternatively, "What are the most important technologies that have emerged in the last, say, half century and what impact have they had on the poor?" The first approach would probably lead to a primary focus on agriculture and the so–called "green revolution" technologies (GRTs), since most of the poor in the developing world still depend on the land[3]. By one estimate (Spillane, 2000), there are some 1.05 billion farmers in the developing world. In this case, there is little doubt that the technologies have contributed to reducing poverty, but the question often asked is "With the productivity gains these technologies have made possible, why are there still so many hungry, malnourished, poor people?" The second approach might lead one to focus first on information and communication technologies (ICTs), the latest "general purpose technology"[4], in which case the impact on the poor is less direct and less obviously positive. To the extent that ICT contributes to overall productivity growth and distribution does not worsen, the effect on the poor should be positive. To the degree, however, that ICT's effective use demands skilled labour, its benefits to the poor, as producers, may be limited or even negative in the event that widespread, skill–biased technical change should substantially depress aggregate demand for unskilled workers. There remain the possible benefits to the poor as consumers of goods and services that can be delivered more efficiently using ICTs (e.g. health care, government services) or as users of cheap information available through ICT to command higher prices, reduce or hedge risks and resolve technical problems (e.g. pest management, veterinary health).

By virtue of a technology's having been adopted, one can assume that expected benefits to the adopter exceed the costs. Thus, a technology observed as ignored by poor people does not pay at its current cost. In the case of GRTs, for example, a small–scale farmer on an arid piece of land may decide not to adopt high–yielding varieties, considering the modest expected yield improvement, while the investment might well be justified under more favourable rainfall conditions or on irrigated land. The policy question, in this case, is whether greater investment in public agricultural research on varieties better adapted to arid conditions is the best use of scarce resources, or whether the poor farmer on marginal land would be better served through other public investments.

For public policy, three sorts of technology choices need to be considered. The first follows from the preceding example. How much should the government (and the international donor community) support science and technology development in the interests of poverty reduction and, within the agreed budget envelope, how should that support be allocated? Second, what sort of legal and policy environment is needed to ensure adequate incentives to poverty–relevant research and development by commercial interests, while at the same time providing timely access to the fruits of R&D by poor people? The appropriate framework for protection and transfer of intellectual property rights is the key issue here. Finally, how does the broader economic policy environment affect the rate and the direction of technology development? Especially with respect to this last question, it is worth remembering that, while in some cases poor people themselves are the agents making technology adoption decisions (e.g. small farmers and modern seed varieties), in many others the poor are merely affected by the technology–adoption decisions of others (e.g. factory owners who introduce new methods of production that alter labour demand). Standard economics would prescribe that government policy not significantly bias choice of technique against "natural" factor endowments — e.g. by measures that favour capital–intensive technology in a labour–abundant economy. In a comparative–static framework, this prescription would be best for the poor, who are the ones hurt by policies biased against employing unskilled labour. There is a possible tension that needs to be recognised, however: in such an economy, the returns to education will likely be lower than in one where technology choice creates strong demand for skilled labour and thus also incentives to invest in human capital. This, in turn, may limit future growth prospects.

Even for the poor farmer who controls the decision of what to grow with what technique, his rewards depend on the constellation of demands, output levels, and production technology choices by a host of other agents. Similarly, what may appear profitable to the individual farmer at a given time may end up becoming unprofitable if enough others make similar choices, affecting appreciably total supply and market prices. Still, the early adopter has the prospect of earning technology rents during the transition, and this continues to serve as inducement to innovation. The embedding of individual technology choices in the larger economic and social structures, and the influence of other actors' choices on the individual returns to technology adoption call for a general equilibrium (or at least economy–wide) analysis.

A Macro Perspective on Technology and Poverty

Economists normally discuss the macroeconomic impacts of technological change in terms of productivity growth. In the standard Solow growth model, in the long run, a country's income can grow only through technical change. The macroeconomic treatment of technological progress is not especially concerned with specific technologies and their characteristics, or with the impacts of technological advance on income distribution. A partial explanation of the neglect of income distribution is that pioneer researchers in the field of development economics expected a "trickle–

down” effect. With time, growth would lift the whole population out of poverty — an idea that crystallised in the so–called Kuznets curve. The focus lies on aggregate productivity growth, with technological progress in Solow modelled as an exogenous parameter shift in an aggregate production function, and with much recent growth theory (beginning with Romer, 1986) intent on endogenising it. Steady improvements in average per capita income will, with unaltered income distribution, lift a progressively larger share of the population out of poverty. As Bruno *et al.* (1998) point out, however, the initial income distribution has a strong bearing on how far productivity growth benefits the poor. Also, the income distribution need not remain constant, and the benefits to the poor depend strongly on whether it improves or deteriorates with growth.

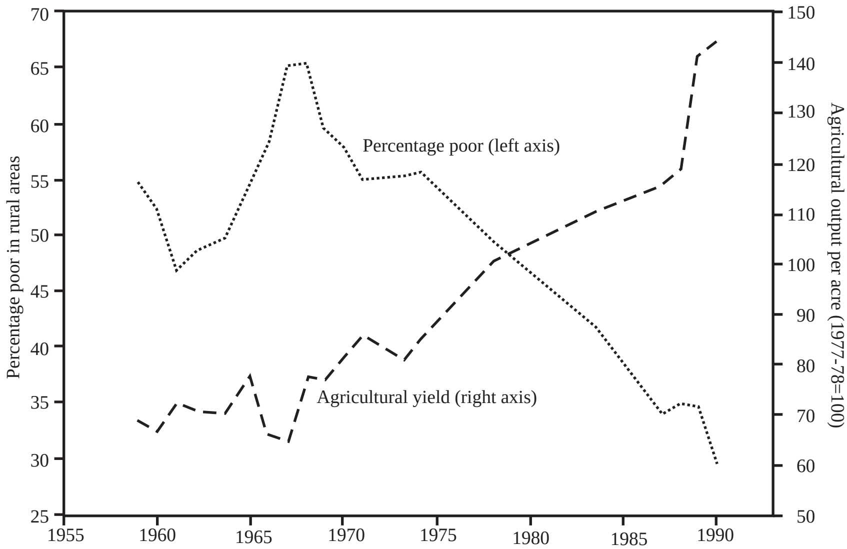
Evidence on the distributional changes accompanying growth is mixed, but historical evidence for a number of countries shows only gradual change over fairly long periods. In India, for example, the income Gini remained almost constant from 1951 through 1992, with a mean of 32.6 and standard deviation of 2.0 (Li *et al.* 1998). In those cases at least, stimulating growth should be a boon to poverty reduction[5]. Dollar and Kraay (2000) confirm this. Using panel data for a sample of 80 countries over several decades, they find that the income of the poorest quintile of the population rises roughly in line with average per capita income. In that respect, as the title of their paper suggests, growth *is* good for the poor.

As Ravallion and Datt (1999) point out, however, even if cross–country regressions show a strong link between average growth rates and poverty reduction, the poverty–reducing impact of a given growth rate shows considerable variance. The initial distribution matters, and that distribution (as measured again by the Gini) varies widely across countries, from 61.9 in Honduras in 1968 to 17.8 in Bulgaria in 1976. For instance, Ravallion (2000) estimates from a sample of 117 periods between household surveys in about 50 developing countries that the elasticity of poverty with respect to growth is about twice as high (in absolute value) for the distribution–corrected rate of growth as it is for the ordinary growth rate. What may matter more than the initial income distribution is the asset distribution, including physical assets, access to financial capital, and human capital.

The direction of change in distribution accompanying growth also matters. In countries where income inequality rose with growth, the median rate of decline in dollar poverty was 1.3 per cent per year, but in those where reduced inequality accompanied growth, the median rate of poverty reduction was seven times higher, or around ten per cent per year (Ravallion 2000). Whether growth is accompanied by widening or narrowing inequality depends, in turn, on a range of factors, including initial conditions like human capital endowments, access to credit by low–income households, and policies that may influence the distribution of benefits from growth.

The sectoral composition of growth also makes a difference to poverty reduction. Ravallion and Datt (1996) provide evidence for India that faster agricultural growth is strongly and unconditionally associated with both rural and urban poverty reduction (see Figure 1). The same is not true of faster growth in the manufacturing sector, whose benefits to the poor depend on a variety of initial conditions like educational attainment, infrastructure, urbanisation, and agricultural productivity.

Figure 1. **Agricultural Yields and Rural Poverty Rates in India**



Source: Ravallion and Datt (1995)

Insofar as technological progress raises farm and non–farm productivity growth, and assuming in the latter case that favourable initial conditions are in place, technology should benefit the poor. The question, though, is one of degree. How important is technology relative to other causes in explaining poverty alleviation? In developing economies — few of which are on a steady–state growth path — other important factors can affect growth prospects. Widespread distortions, market imperfections, and institutional deficiencies leave much scope for reform–induced growth acceleration, at least over some transition period.

Agricultural Technology Innovation and Diffusion

The Green Revolution

The GRTs have had probably the most dramatic effect on poverty in the developing world of any technologies developed over the past half century. The effects were not immediate, and much early literature suggested that the benefits would accrue primarily to better–off farmers. As Lipton (2001) points out, a dramatic reduction in malnutrition has occurred in much of Asia and Latin America as well as parts of Africa, despite a trebling of population. In India, between 1977 and 1993 alone, the percentage of children under five who were malnourished (measured by weight) fell from 71 to 53 (WDI, 2000).

The GRT package as originally introduced in Asia in the mid–1960s included high–yielding crop varieties (HYVs, traditional as well as hybrid), irrigation and nutrient and pest management (largely through application of chemical fertilisers and pesticides). HYVs, with shorter growing seasons, also offered greater opportunity for multiple cropping. Given the working capital requirements, the dependence on irrigation and the uncertainties associated with early adoption, it seems logical that wealthier farmers pioneered the use of GRTs. The early benefits to the poor went more to agricultural labourers and those engaged in off–farm employment, as well as to the urban poor in terms of lower food prices. For non–adopting smallholders, the effect of such price declines was mostly negative, although traditional varieties generally continued to command a quality premium.

A second phase of GRT development — dated roughly from the mid–1970s — aimed at extending benefits to poorer farmers through, for example, development of pest–resistant varieties and those capable of withstanding soil stress (e.g. acidic soils). India in the 1980s adopted modern cereal varieties on an additional 20 million hectares, a figure comparable to that at the 1967–75 height of the green revolution; land area planted to HYVs now greatly exceeds irrigated land area (Byerlee, 1996). While only two modern wheat varieties spearheaded the green revolution in India, by the mid–1990s the national research service was releasing eight new varieties a year for 20 different types of agro–climatic environment. With the extension to less favourable environments, however, has come a slowdown in yield growth.

Lipton and Longhurst (1989) cite the example of the Indian Punjab to illustrate the dramatic transformations that have occurred with the widespread adoption of GRTs. Between crop years 1965–6 and 1980–81, the area planted to wheat and rice increased from 38 per cent to 59 per cent of gross cropped area; wheat yields rose by 120 per cent and rice yields by 174 per cent; and grain output grew twice as fast as population, with less year–to–year variation, somewhat lower prices and more employment per hectare. In short, modern varieties "do tend to reach 'small farmers', reduce risk, raise employment, and restrain food prices", all of which should redound to the benefit of the poor. Yet, at the time, the benefits in terms of poverty reduction appeared modest. The authors seek to resolve this paradox. They observe that the poor are increasingly land–poor and dependent on wage labour. They argue that the benefits to the poor as consumers (lower food prices) are captured largely by their employers, who can pay lower wages. The benefits to the poor as labourers are mitigated by farm mechanisation, increased use of herbicides and weak linkages between the modern varieties and the non–farm sector.

Some more recent studies of GRTs in the PRC paint a less bleak picture of their effects on poverty and income distribution. There are two broad approaches to analysing these effects. One looks narrowly at crop income, considering the differential rates of income growth of adopters and non–adopters of modern varieties. The other takes a broader view of impacts on total household income, across adopter and non–adopter households. Huang and Rozelle (1996) focus on Chinese rice productivity, seeking to estimate how much of its growth can be attributed to post–liberalisation institutional innovation (the decollectivisation of agriculture), how much to technology, and how the latter interacted with the former. They find that technology contributed 60 per cent of the growth in yields over 1975–90, while institutional change contributed 22.3 per cent. Moreover, after 1984, practically all of the positive contribution to rice yields came from technology, notably adoption of hybrids, more than offsetting negative effects of environmental stress and rising input prices.

Lin (1999) takes the broader view of technology adoption, focusing on how it affects total household income in both adopter and non–adopter households. He hypothesises that those who choose not to adopt the modern varieties (e.g. of rice) rationally prefer to devote more resources to other income–generating activities, whether in or outside of agriculture, where they enjoy a comparative advantage. The study draws on household survey data for five counties of Hunan province in the PRC, which has long had one of the highest adoption rates of hybrid rice varieties in the world. In all but one county the Gini coefficient on total household income is smaller than that on rice income alone, which is consistent with the view that households not able to profit from rice production (for reasons of technology, land endowment, or other factors) specialise in other areas where they can earn higher returns. The main trade–off in the technology adoption decision seems to be between rice and non–farm income — i.e. planting hybrids has a significantly positive effect on rice income and a significantly negative effect on non–farm income. At the same time, modern variety adoption apparently has no significant effect on total household income, while such variables as size of landholding, number of actively employed household members, and average years of schooling do.

The schooling–income link in Lin comes from schooling's effect on non–farm income, while the effect on farm income appears to be negligible, controlling for hybrid adoption. It is possible, of course, that schooling significantly affects the choice whether or not to adopt (or the timing of when to adopt)[6], but Lin cannot test for this. Still, the finding seems at least consistent with other studies, which find that the main effect of schooling in farm households is not on crop productivity *per se* but on allocation decisions — e.g. choice of cropping mix and mix of farm and non–farm activities. (See Feder *et al.*, 1985, for a review; and Taylor and Yúnez–Naude, 1999, for microeconometric evidence from Mexico.) These are essentially entrepreneurial decisions. Pomp and Burger (1995) offer another piece of supporting evidence. They find in Indonesia that education levels significantly affect decisions by farmers to grow cocoa (essentially diversification decisions), and that other farmers are more likely to follow the lead of educated early adopters than of uneducated ones, suggesting greater trust in their entrepreneurial judgement.

If the poor are also the less educated, then they will presumably have less capacity to make optimal allocation decisions. A possible policy implication of this is that, given the choice between investing in new crop varieties tailored to the growing conditions of the poor and investing in their education, preference should be given to the latter. In this way, not only are the poor given more options but they also are afforded a stronger basis for choosing among them.

There is good reason to suppose that agricultural productivity gains matter more to poverty reduction than do productivity gains in other sectors of the economy. First and foremost, this derives from the heavy weight of food items in the consumption baskets of the poor. Food in general and staples in particular represent over 70 per cent and 50 per cent, respectively, of the consumption expenditures of the dollar poor. Second, the poor are much more likely than the non–poor to make a living from agriculture and/or other rural employment. About two–thirds of the world's 1.3 billion poor people live in rural areas, and most are employed in agriculture. Third, the poor depend heavily on labour income, and for a given growth in output the agricultural sector tends to employ more labour than other sectors, both directly and indirectly (in the form of labour–intensive rural non–farm services) (Lipton, 2001).

Using a computable general equilibrium model, with stylised rural economies and poverty characteristics for Africa, Asia, and Latin America, de Janvry *et al.* (2000) simulate the effects on poverty of an agricultural technology improvement, defined as a ten per cent gain in agricultural total factor productivity (TFP). In Africa, the benefits to the poor accrue directly to smallholders in terms of improved own consumption and income; in Asia they accrue mostly to agricultural labourers in terms of higher real wages and greater off–farm employment opportunities; in Latin America they accrue mostly in the form of cheaper food prices for the rural and urban poor.

The Gene Revolution

The biochemical green revolution has stalled, with depressed crop prices dampening incentives to farmers and increased input demand raising fertiliser and agrochemical prices while contributing to water scarcities. Yield improvements in developing countries have slowed significantly, from an average of 2.9 per cent per year for cereals in 1967–82 to 1.8 per cent per year in 1982–94 (de Janvry *et al.*, 2000). The latter yield growth, if sustained over the next 25 years, would just about satisfy the projected 59 per cent growth in demand. With existing technologies, however, the likelihood of sustaining such growth would appear to be low.

The so–called Gene Revolution of biotechnology does not offer any quick fix to this secular yield slowdown. The potential applications of biotechnology are of two major sorts: to reduce costs of varietal improvement by employing molecular markers and improved diagnostics for more precise selection of plants that carry desirable traits, and to allow transfer of genes from unrelated species to provide traits that would not be available through conventional breeding (Byerlee, 1996). In cereals research, transgenics is most advanced in rice so far, where eight new genes for pest resistance have been inserted and varieties carrying some of these genes are likely to be released by decade's end in Asia. Both sorts of application offer greater genetic variety, yield stabilisation and reduced pesticide use, but they are not likely to have a major impact on yield growth.

Rice breeding in West Africa provides a promising example of the potential biotechnology may hold for poor farmers. The West Africa Rice Development Association was established in 1971 as an autonomous intergovernmental research association with a mission to strengthen Sub–Saharan Africa's capability for technology generation, technology transfer and policy formulation, in order to increase the sustainable productivity of rice–based cropping systems while conserving the natural resource base and contributing to the food security of poor rural and urban households. It has adapted Asian HYVs to African circumstances, making them resistant to local pests and diseases and tolerant of poor nutrient conditions and mineral toxicity. Farmers play an important role in disseminating the seeds through traditional village systems of barter and sale. As a result, the hybrid varieties have diffused rapidly.

De Janvry *et al.* (2000) note a number of potential benefits of plant biotechnology to the poor. They include reduced risk (e.g. of pest infestation or drought–induced losses); improved storability (hence reduced wastage) due to pest resistance and delayed maturation; nutritional improvements (e.g. through genetic introduction of micronutrients); and health benefits due to reduced exposure to agrochemicals and development of new vaccines. Apart from biosafety risks, biotechnology may pose some risks to the livelihoods of poor people, for example by reducing labour demand for weeding with herbicide–resistant varieties. Perhaps the greatest risk is that the crops of poor subsistence farmers will be bypassed by biotechnology innovations. There is also a risk that, if terminator genes are used to enforce intellectual property rights, costs to farmers of seeds could increase markedly.

One of the most promising avenues of agricultural biotechnology research is the self–enrichment of staple food varieties with micronutrients (e.g. vitamin A, iron, zinc), whose deficiency in many poor people's diets is known to cause serious health problems (Bouis, 2001). Annually an estimated 250 000–500 000 pre–school children go blind from vitamin A deficiency, and about two–thirds of them die within months of going blind. As Bouis points out, good nutritional balance is as important for disease resistance in plants as it is in humans, and the efficient uptake of micronutrients from the soil contributes to such resistance. So, such varieties could reduce dependence on fungicides to maintain yields at the same time that they improve human nutrition. Once again, research is most advanced on rice. Bio–availability tests began in 2000 on an aromatic variety (IR68–144) with twice the iron (after milling) of standard IRRI[7] varieties; it is also early maturing, high–yielding and disease–resistant.

The Heretofore Excluded

Some agricultural areas have been largely bypassed by both phases of the green revolution. These include areas generally classified as marginal for crop production — e.g. areas prone to frequent drought and, in the case of rice, with little water control; areas with poor infrastructure and no access to markets (most often affecting maize in Africa and parts of Latin America); areas where quality trades of traditional varieties outweigh the yield advantages of HYVs (as for rice in Thailand); and areas where the research system has been unable to develop varieties with yield advantages. Several of these area types happen, not by coincidence, to have an especially high incidence of poverty.

Lin (1999) questions the validity of suggestions (citing Lipton and Longhurst, 1989) that future agricultural research needs to give more consideration to the distributional implications of modern varieties. In his view, household resource reallocation decisions in the face of changing relative rewards will mitigate most if not all adverse distributional impacts of differential adoption of food–crop innovations. For those who find cereals production less profitable, investment in rural roads and other infrastructure may yield greater benefits (by providing better links to markets and encouraging development of off–farm employment) than investment in raising cereals profitability.

Lin himself is quick to caution against sweeping generalisations of the rather sanguine conclusions drawn from limited evidence on one province of the PRC. What is clear is that, if widespread adoption of GRTs were sufficient to alleviate hunger, malnutrition, and poverty, the rate of poverty would have declined far more rapidly than it has in major adopting countries. As Lipton and A. Sen have long emphasised, the issue is not simply one of increased food production but of entitlements of the poor to food, as manifested among other ways in the paid employment opportunities of the growing ranks of the landless and land poor (including the urban poor).

Arguably, within agriculture, certain types of research and investment relatively neglected in the past — like improved systems of water management — will assume greater importance in the future (Lipton, 1999). Worsening water scarcities in many countries will likely become a more severe constraint on continued yield growth, and they may even render current production practices unsustainable. While investing in development of drought–resistant crop varieties offers one route to addressing the water problem, the payoff could be far greater to investment in developing and putting in place better water–control and conservation techniques.

One cautionary note is appropriate. New biotechnology may play a role in addressing the food security, nutritional and health problems of the poor in the coming decades, but other factors may be more important. As a recent *Financial Times* article notes in summarising discussion at an international agricultural forum: "While US and European companies hawked technology as the solution to under–nourishment in developing countries, international agencies and national representatives saw a host of more immediate and mundane problems…inadequate farm size, lack of investment, trade distortions and subsidies in the industrialised countries" (Nikki Tait, *Financial Times*, 30 May 2001).

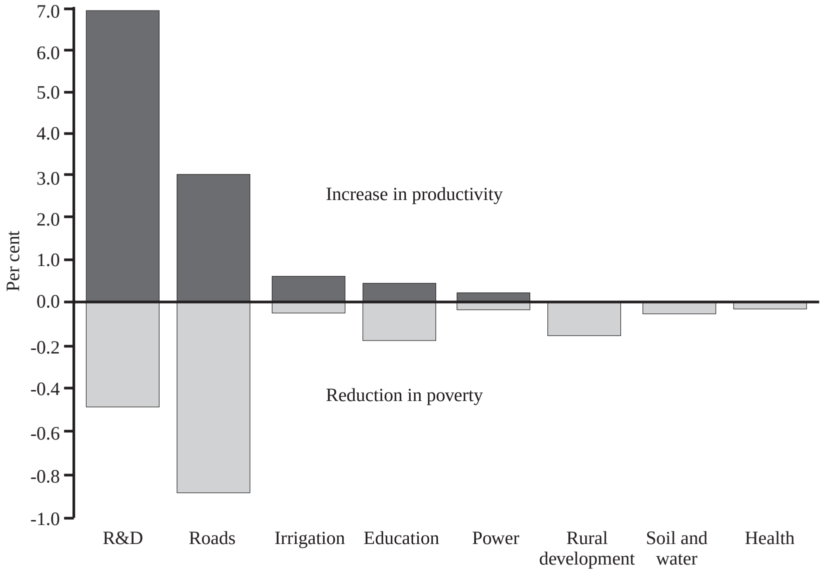
Non–Farm Productivity Growth and the Poor

The impact on poverty of productivity growth in non–farm activities is more ambiguous than that of agricultural productivity growth. Ravallion and Datt (1996) find that the sectoral composition of growth matters to poverty outcomes — e.g. whether the growth dynamic encompasses agricultural and rural non–farm activities or is confined primarily to the urban industrial sector, in which case the poverty impact is limited. Ravallion and Datt (1997) find that agricultural growth unconditionally reduces poverty across Indian states, but the effect of non–farm output growth on poverty is conditional on initial literacy rates, agricultural productivity, the degree of urbanisation and the size of the rural–urban income gap. The importance of initial literacy rates is consistent with findings of Lin (1999) for the PRC that years of schooling are a significant determinant of non–farm household income. If very few have schooling, then the bulk of the income from non–farm employment will accrue to the few. High literacy and schooling rates should spread income gains more widely.

Lin (1999) decomposes Hunan county–level Gini coefficients for total household income into a rice income Gini, a non–rice agricultural income Gini, and a non–farm income Gini. A striking result is the much higher Gini on non–farm income than on the two types of agricultural income. Even though non–farm income represented only about a quarter of total household income in the sample, it made an identical contribution to rice to overall household income inequality. Thus, as rural households come to depend less on farming and more on non–farm activities, we would expect rural inequality to increase significantly. Clearly, though, a widening distribution need not imply increasing absolute poverty. One can imagine a situation in which the relatively uneducated, land–poor come to derive a growing share of their income from non–farm employment, with their sheer numbers competing wages down, while the educated few leave agriculture behind for better–paid employment in non–farm businesses, professions, etc. At the margin, the low–skilled wage earners would presumably be at least as well off as if they had stayed in agriculture, while a substantial number are probably better off. What is the probability of their moving out of poverty?

That depends on some of the other factors identified by Ravallion and Datt (1997). For instance, the productivity of the agricultural sector is likely to affect the returns to non–farm employment insofar as a more dynamic agriculture will generate greater local intermediate demand for inputs and services as well as construction (housing, farm structures) and final consumption demand. The proximity to markets — as reflected in the condition of rural infrastructure and the degree of urbanisation — is also an important determinant of the returns to non–farm employment. Not only does proximity to urban areas raise the possibility of temporary employment–related migration, but it also facilitates the spill–over of labour–intensive industrial activities from cities to their lower–cost hinterlands. The following figure from Fan *et al.* (1999) illustrates the strong complementarity between the productivity and poverty–reduction effects of rural road investment in India. This has much to do with providing direct employment to the poor on road projects and something to do with getting traditional food crops to market and critical inputs delivered to farmers in a timely fashion. It also has a great deal to do with allowing greater diversification of the rural economy, including in agriculture (e.g. into vegetables, fruits and other perishables for urban markets) and into non–farm production, and with the cheapening of manufactured imports from the cities.

Figure 2. **Increases in Growth of Productivity and Reduction in Poverty as a Result of Additional Government Expenditure**



Note: Based on spending of an additional Rs 100 billion in 1993 constant prices.
Source: Fan *et al*. (1999).

Differential Rates of Technical Progress across Sectors

Having looked at technological change — reflected in productivity growth — in agriculture and non–agriculture separately, let us return to the big picture, considering the economy–wide effects of differential productivity growth across sectors. First, do sectoral TFP growth rates differ over long periods of time and, if so, how? A common and longstanding assumption among many economists has been that agricultural productivity growth lags that of manufacturing, because of either a more limited scope for division of labour (Adam Smith) or diminishing returns to the fixed factor, land (David Ricardo). Martin and Mitra (2001) examine the evidence, exploiting a new dataset (constructed by Larson and Mundlak) on capital stocks in agriculture and manufacturing for a large sample of countries over a quarter century beginning in 1967. They consistently find the opposite result, whether with a Cobb–Douglas or a translog production function specification — agricultural TFP growth significantly exceeds manufacturing TFP growth. In a translog specification, the former averaged double the latter for low–income and middle–income developing countries. There is also strong evidence of productivity convergence to US levels in agriculture but less in manufacturing. They suggest that one reason for the finding may be that the dataset covers essentially the period of the green revolution. Be that as it may, what do these trends imply for poverty reduction?

Higher productivity growth does not necessarily imply higher value–added growth; indeed, we know that, with economic development, agriculture's share of GDP tends to shrink, in part as a result of Engel's law. The relative growth of industry, however, would appear to owe more to capital deepening and resource reallocation from agriculture — including through rural–to–urban migration — than to faster productivity growth. Whether this benefits the poor depends to a degree on whether the reallocation results from unaided market forces or is abetted by industry–biased government policy. In the former case, while manufacturing may on average have a higher capital–labour ratio than agriculture, the sort of manufacturing that thrives in a labour–abundant economy should be of the labour–intensive variety. Government policy, on the other hand, is usually designed to give a head start to more capital–intensive endeavours, with more adverse consequences for non–farm employment demand.

Whether the economy is a small open economy or a large, presumably less open one can also make a difference. In the former case, with prices determined on world markets, the effect of differential sectoral rates of productivity growth should be primarily of a Rybczynski kind, i.e. with the faster–growing sector drawing resources away from the less dynamic one, causing it to shrink. (Is 1980s Chile an example?) Where the economy is large (and closed), the effects are more likely to be felt through movement of the commodity terms of trade against agriculture, transferring resources to industry. In this case, the effects on the poor depend heavily on the nature of non–agricultural labour markets, in particular their degree of segmentation and any resultant entry barriers to rural migrants.

Information and Communications Technology for the Poor

Distance — remoteness from markets — remains strongly associated with poverty. While the last several decades have seen major advances in international freight and passenger transport, transport within poor countries has not often seen comparable improvements. To a degree, telecommunications is similar, but there are also important differences, resulting notably from their very different technological trajectories. Land transport remains much the same today as a half–century ago, but telecommunications is vastly different. Still, the problem of connecting remote areas and their poor inhabitants economically to population centres remains, whether the connection is a road or a telecommunications mainline. Understanding ICTs' potential to improve poor people's welfare requires answers to three questions:

— What are the principal sorts of information that poor people need to make them better off?

— Which of that information is currently not being supplied effectively (on time, in a readily usable form)?

— Can ICTs remedy the deficiency cost effectively?

A few examples help illustrate the sorts of information available with ICTs that can benefit the poor:

— In India, agricultural workers paid in kind can ensure fair wages by having independent access to information on the market price of rice;

— Farmers can check seed prices and decide on that basis whether to plant hybrid varieties; and

— Sugar farmers can contact an entomologist for advice on pest management.

In each case, timing is crucial and the timeliness of the information available with ICTs (whether by telephone or the internet) gives it its value. Ironically, we tend to think of the expression "time is money" as a product of advanced capitalism, but timing is perhaps even more crucial for the poor farmer. Selling a crop at just the right time can make a big difference for profits.

Another popular conception is that ICTs are particularly well suited to advanced capitalist economies with large service sectors that generate heavy demands for information processing, management and sharing. Perhaps, but another stylised feature of developed economies is that their markets work reasonably efficiently, with low transaction costs. Developing economies, on the other hand, have pervasive market imperfections and, presumably, high transaction costs. There is little systematic evidence to support this hypothesis but much of the anecdotal kind (cf. Goldstein and O'Connor, 2000, for a survey). Assuming it is so, then ICTs (in particular, internet–based e–commerce/e–business) have greater efficiency–enhancing potential there than in the developed countries. The significance of this for the poor appears ambiguous. On the one hand, if middlemen who capitalise on an information monopoly cause the inefficiencies, both the consumer and the poor producer — whether of agricultural goods, handicrafts, or light manufactures — could benefit from disintermediation, sharing the cost savings between them. On the other hand, some poor people — e.g. truck drivers, porters, and warehouse workers — no doubt depend on the distribution sector for their livelihoods; they may be adversely affected by sectoral cost–cutting in the event of a profit squeeze. While for the moment only an intuition, the first effect on the poor would seem the more important. The next section takes a formal look at how transactions–cost–reducing technologies (transaction technologies for short) may affect both overall economic efficiency and income distribution.

A further non–trivial contribution that ICTs could make to help the poor is in realising cost savings through rationalisation of government functions. Areas of considerable wastage in many countries include non–competitive procurement (e.g. of vaccines and medicines, school textbooks, building materials and construction services), poor storage, poor inventory management and erroneous demand projections, most of which are amenable to amelioration through ICT use (Bloom *et al.*, 2000).

One perhaps undervalued contribution of ICTs to human development and, potentially at least, to the welfare of the poor lies in facilitating advanced scientific research in a whole range of disciplines but notably in genomics, biotechnology and their application to drug development and agriculture. The current pace of technical progress in these fields would have been inconceivable before the advent of powerful electronic computers. The internet and other technologies for sharing large–scale databases have tremendously facilitated collaborative scientific research[8].

Transaction Technologies: Theory and A Simple Numerical Model

Transaction Costs Theory

The seminal work of Coase (1937) sought to explain the simultaneous existence of markets and firms, reasoning that if markets were efficient forms to organise production and exchange there would be no need for firms to emerge, and if firms had pervasive cost advantages over markets, we should observe a single giant firm producing all that is demanded. His fundamental intuition was that differential transaction costs across activities explain why both firms (or institutions) and markets exist. In certain types of activities, costs of market transactions are sufficiently high to warrant the internalisation of exchanges within firms, while for other types markets operate with low transaction costs. This work has spawned a voluminous literature, both theoretical and empirical[9], that is not without its critics. In Goldberg's (1985) words, explaining economic phenomena by appeal to transaction costs "is the all encompassing answer that tells us nothing".

Another approach starts from the premise that transaction costs are pervasive and asks how exchanges take place in markets affected by variations in transaction costs within a standard general equilibrium framework. In an effort to enrich the theory of general equilibrium as formulated by Arrow and Debreu (see Debreu, 1959), a few authors[10] have studied how it should be modified to incorporate transaction costs and what consequences such a modification would have for the major predictions of the standard theory. In Foley's words, "the key aspect of the modification I propose is an alteration in the notion of 'price'. In the present model there are […] a buyer's and a lower seller's price [and their] difference yields an income which compensates the real resources used up in the operation of the markets" (Foley, 1970) When the operation of a market needs intermediaries that provide information or other services to buyers and sellers so that they can complete a transaction, then these intermediaries would generate an income by charging a transaction fee (= cost) equal to the value of their marginal product.

Another form of transaction costs has been considered in international trade and explicitly incorporated into models since Samuelson's 1954 article on transport costs. The basic idea here is that trade involves transaction costs and that these may be simply thought of as a fraction of the traded good itself, as if "only a fraction of the ice exported reaches its destination as un–melted ice". This "iceberg model" clarifies how a reduction in transaction costs saves real resources and makes an economy more efficient.

In practice, transaction costs may arise from a variety of sources. Some may be amenable to technology — like high transport and distribution costs — and some (e.g. reduced bureaucratic red tape and corruption) may require policy intervention.

A Simple Numerical Model with Simulations for India

This section examines the poverty effects of changes in transaction costs, using numerical simulations based on a theory–consistent general equilibrium model calibrated on data for India. It uses 1994 data on production, consumption, factor and intermediates use, aggregated to a two–commodity, two–factor, two–household classification[11]. It abstracts from international trade and focuses on a closed economy. The introduction of import and export flows, while making the prices of tradeables exogenous and determined in world markets, would not affect the determination of factor prices (unless factors are internationally mobile). Technology shocks are not modelled as exogenous productivity changes, but as alterations of a transaction–cost mark–up.

Production. The economy produces two goods, an aggregate primary commodity (mainly agriculture, A) and a composite manufacturing–service commodity (B), using intermediates inputs in fixed (Leontief) shares and combinations of labour and capital in a Cobb–Douglas constant returns to scale technology as follows:

$$Q_i = \eta_i L_i^{\alpha_i} K_i^{1-\alpha_i} \qquad \text{with the commodities index i = A, B} \qquad (1)$$

where Q_i represents the quantity produced of the two goods, h_i a parameter standing for the sector–specific technical level, and a_i and (1– a_i) the Cobb–Douglas output elasticities with respect to labour and capital. Factor–neutral technology shocks similar to those mentioned above would entail changes in the parameter h_i.

Factor markets. Assume full employment of fixed endowments of capital ($\overline{K}$) and labour ($\overline{L}$), so that their supplies will be completely inelastic with respect to their prices. These are thus determined by firms' demands that, in competitive markets, are equal to their marginal product in value:

$$w = \alpha_i Pva_i \frac{Q_i}{L_i} \qquad \text{i = A, B} \qquad (2)$$

$$r = (1-\alpha_i) Pva_i \frac{Q_i}{K_i} \qquad \text{i = A, B} \qquad (3)$$

where w and r are the wage and rental rates respectively, and *Pva* is the value–added price, i.e. the commodity sale price minus intermediates costs.

Transaction Costs are modelled as a mark–up on commodity prices. This is equivalent to an excise tax or a transport margin and thus does not increase with the value of the exchanged commodity but is proportional to the quantity exchanged:

$$Pt_i = P_i + t_i \qquad \text{i = A, B} \qquad (4)$$

where revenues generated by the wedge t_i between the seller and buyer's price are equal to $\sum_i t_i Q_i$, and are used to buy transaction services from sector B of the economy.

Therefore, in this case, sector B receives income by selling its *normal* output plus transaction services.

Consumption. The model includes two households, one rural (R) and one urban (U), that receive incomes from selling factor services and demand commodities via optimisation of a Cobb–Douglas utility function. Households are thus differentiated by their consumption patterns and their ownership shares, with the urban household demanding more of commodity B, owning a larger share of capital and representing the rich household. Derived consumption demands are as follows:

$$Qd_{H\,i} = \beta_{H\,i} \frac{Y_H}{Pt_i} \quad \text{with the household index H = R, U and i = A, B} \qquad (5)$$

where *Qd* represents the household–specific quantity demanded, β an utility share parameter, and *Y* the household's income.

Equilibrium Conditions. Factor–market clearing conditions simply state that the sums of factor demands must equal the fixed factor endowments.

$$\sum_i L_i = \overline{L} \qquad \text{and} \qquad \sum_i K_i = \overline{K} \qquad \text{i = A, B} \qquad (6)$$

Commodity prices are derived from the equality of supply and demand where the latter includes final consumption as well as intermediate and transaction service demands:

$$Q_i = \sum_H Qd_{H\,i} + \sum_j a_{i,j} Q_j + Qt_i \qquad \text{i = A, B} \qquad (7)$$

where $a_{i,j}$ represents the Leontief input coefficients for intermediates and *Qt* the quantity of transaction services. As mentioned above, these are provided exclusively using sector B's technology and their total value is equal to the *revenues* from the transaction cost mark–up.

In this simple model, one can solve for household income distribution based on household factor ownership and changes in factor rewards. Given fixed factor ownership shares for the rural and urban households and setting a poverty line, it would not be difficult to calculate absolute household poverty measures. Considering household–specific absolute poverty indices has the advantage of allowing one to trace the effects of changes in transaction costs not only on the supply/income side, but also on the demand/expenditure side.

This simple general equilibrium model can be used to conduct some basic experiments aimed at investigating the analytics of the link between transaction costs and poverty. The following numerical results should not be considered exact estimates, but just indications of the potential magnitude and direction of that link. The crucial characteristics of the initial data for India are shown in Table 1, where it is possible to observe the following:

Table 1. **Initial Data: Main Characteristics**

Sectoral Variables	Sector A	Sector B
K/L	0.81	1.28
Transaction Costs *ad valorem* (per cent)	19	12
Intermediates as per cent of Production	43	44
Transaction Services as per cent of Output	0	26
Ownership Shares (per cent)	**Labour**	**Capital**
Rural Households	56	40
Urban Households	44	60
Total	100	100
Consumption Shares (per cent)	**Rural Household**	**Urban Household**
Sector A	71	58
Sector B	29	42
Total	100	100

Source: Authors' calculations based on Indian input-output data and expenditure surveys.

— Sector A is labour intensive and uses more or less the same percentage of intermediates as sector B;

— Exchanges, among producers as well as between producers and final consumers, of the commodity produced by A entail larger transaction costs than those of commodity B; and

— Transaction services are produced exclusively by sector B and account for about a quarter of its total output.

— Compared with urban households, rural households own a larger share of labour and a smaller one of capital and consume far more commodities of type A than of type B.

Most of these numbers are direct calculations from India's national accounts and input–output table, but transaction costs have been estimated using raw data on inputs of transport/communication/distribution services by sector, with an additional mark–up for sector A to reflect the assumed greater remoteness from markets and more limited access to basic services such as banking. Although these preliminary estimates need to be improved, it seems reasonable to expect that, at a similar level of intermediate use, sector A's agricultural commodities and rural light manufacturing (such as textiles) have to incur larger transaction costs than typical sector B commodities. Indeed, post–harvest losses in agriculture remain a widespread problem.

The first experiment, simulating a situation where new transaction technologies are adopted, consists of a shock that reduces the transaction cost mark–up by 50 per cent for both commodities. Its main effects are summarised in Table 2, and the causal relationships work as follows. The initial shock reduces the wedge between the buyer and seller's price and the *revenues* from transaction cost mark–ups. This immediately affects those intermediaries who were delivering transaction services according to the technology of sector B (notice the reduction of 46 per cent in the value of transaction services), and frees labour and capital resources. Given that sector B is more capital intensive than A, its overall reduction releases capital at a faster rate than that needed to expand the labour–intensive sector A, and this entails an increase in the wage–to–rental ratio. Even with *no sector bias* in the reduction of transaction costs, a reduction in relative poverty occurs and, due to their factor ownership and consumption patterns, rural households' income and consumption increase faster than those of urban households.

Table 2. **Basic Experiment of Reduction in Transaction Costs**
(Variations in per cent from initial equilibrium)

Output, Sector A	11.8	Rural Consumption of Commodity A	14.3
Output, Sector B	-9.0	Rural Consumption of Commodity B	10.8
Transaction Services	-46.1	Urban Consumption of Commodity A	13.9
		Urban Consumption of Commodity B	10.4
Wage: w	6.1		
Rental rate: r	3.7	Income, Rural Households	4.0
w/r	2.4	Income, Urban Households	3.4

The different sectoral factor intensities largely determine changes in the wage to rental ratio. The initial sectoral transaction–cost mark–ups differ too, however, and it would be interesting to know the relative importance of these two initial differences in explaining the final outcome. To decompose the contribution of each, a set of experiments changes factor intensities and mark–ups in sequence. The four columns of Table 3 answer the following question. What happens when transaction costs are reduced by 50 per cent across all commodities and the economy initially has *a)* no sectoral differences in factor intensities or mark–ups; or *b)* differences in transaction costs alone, or *c)* differences in factor intensities alone; or *d)* differences in both mark–ups and intensities?

Table 3. **Controlling for Initial Differences**
(Variations in per cent, given a 50 per cent reduction in transaction costs)

	a	b	c	d
Mark-up	Equal	Different	Equal	Different
K/L Ratio	Equal	Equal	Different	Different
Wage	3.94	4.90	4.85	6.14
Rent	3.94	4.91	3.03	3.68
w/r	0.00	0.00	1.77	2.38

The results show that factor intensities play a crucial role and that when they are equal across sectors relative poverty does not change with transaction–cost reductions. Yet, as shown by the changes between columns c) and d), differential mark–ups intensify the factor–intensity effect. Even with a proportional 50 per cent reduction in mark–ups equal across sectors, in the situation depicted by the rightmost column, sector A benefits from a larger absolute decrease in the mark–up. This results in a more significant drop in the price paid by the buyers of commodity A and a larger increase in demand, and it raises the relative reward to the factor — labour — used intensively in its production.

Based on this last observation one can in fact construct numerical examples where sectoral factor intensities combined with sector–biased reductions in transaction costs produce worse relative and absolute poverty outcomes. Consider a case opposite to the situation observed in the Indian data, where transaction services are provided by the labour–intensive sector and the reduction in mark–up is confined to the capital–intensive sector. Simple manipulation of the original Indian data can generate such a case and make sector B, the transaction services provider, become labour intensive (with a K / L ratio now equal to 0.6 instead of the original 1.3). Table 4 displays the results for two experiments: *a)* a 50 per cent reduction of transaction costs is applied to all commodities, and *b)* it is applied only to commodity A. The results show clearly that, when labour is used more intensively by transaction services, a reduction in their cost may imply a decrease in the w/r ratio and a worsening in relative poverty. A reduction in absolute poverty, recorded by a reduction in the wage in case *b)*, requires that transaction–cost innovations benefit just the capital–intensive sector.

Table 4. **Can Transaction-Cost Reduction Hurt the Poor?**
(Variations in per cent)

	a	b
Wage	1.51	-0.42
Rent	7.71	4.42
w/r	-4.64	-5.75

To this point, the analysis has focused mainly on the production and income–generation side of the story, but important links between transaction costs and poverty operate on the consumption side as well. It seems clear that whenever transaction costs affect more heavily commodities figuring prominently among those demanded by the poor, a reduction in their price should benefit them. The last experiment demonstrates this. Here, a reduction of transaction costs concentrates on commodity A. Table 5 reproduces the initial experiment in column a), and column b) shows an experiment in which total transaction–cost *revenues* are the same as in a) but transaction mark–ups are reduced only for commodity A. Given that the poor have a larger share of A in their total consumption (see Table 1), this translates into much larger increases in demand for this commodity and in larger incomes (there are no savings in the model).

Table 5. **The Consumption Side**
(Variations in per cent)

	a	b
Rural Consumption of Commodity A	14.3	19.6
Rural Consumption of Commodity B	10.8	2.6
Urban Consumption of Commodity A	13.9	19.0
Urban Consumption of Commodity B	10.4	2.0
Income, Rural Households	4.0	5.1
Income, Urban Households	3.4	4.7

These examples show that the simple analytical structure used here can generate a range of results, depending on whether transaction–cost innovations are heavily sector–biased and/or factor–biased. Thus, the question whether an improvement in transaction costs benefits the poor is essentially an empirical one.

The Role of Institutions in Technology Development and Diffusion to the Poor

While ultimately poor people themselves make the decisions whether to use certain technologies — be they poor farmers considering hybrid seeds or rural Bangladeshi women looking at mobile phones — institutions can play an important role in shaping those decisions. In the case of HYVs, for example, public agricultural extension services have been instrumental in "spreading the gospel" of the green revolution and providing technical advice to adopting farmers. In the private sector, seed and agrochemical companies perform a similar function. Extension services can also play an important role in fostering crop diversification. In Bangladesh, Sen (2001) observes that one reason why local farmers have had only limited success in meeting growing demand for meat and vegetables is that an overburdened extension service has been unable to perform basic soil testing for crop suitability and input requirements on more than half of the arable land, increasing significantly the risk to farmers.

For mobile phones in Bangladesh, the Grameen Bank network provided the institutional infrastructure for extending credit to rural women to lease the phones and for bill collection. The absence of institutional or physical infrastructure can prove a serious hindrance to technology diffusion. This is evidenced, for instance, by the huge wastage of vaccine materials in tropical developing countries lacking adequate refrigeration[12] (Bloom *et al.*, 2000; see also Lanjouw and Cockburn, 2001, for a discussion of the importance of delivery systems for new drugs).

Institutions differ in the degree to which their viability depends on collective action. Markets are at one extreme, where the institution takes shape from the decisions of multiple agents acting more or less independently, although their effectiveness clearly depends on participants' agreeing to a basic set of endogenously generated or externally imposed rules. Competitive markets are not always adequate mechanisms for ensuring a socially optimal level of technology development; neither do they always suffice to ensure optimal diffusion of a technology. For example, development and maintenance of irrigation systems normally involve a high level of social co–operation that has traditionally been organised through non–market institutions. Since access to a complementary input like irrigation water can substantially affect the returns to investment in HYVs, the institutional arrangements for water control and allocation clearly matter to technological outcomes. In a rural economy, property rights in land are often the major source of wealth and hence of local political influence. The land–poor lack political clout. That is why the 2000/2001 World Bank *World Development Report* on "Attacking Poverty" mentions empowerment as an essential condition of poverty alleviation.

For information and communications technologies, the crucial complementary input that many poor people lack is literacy, basic as well as the computer kind. Arguably, the former is by far the more important, as many users of computers and the internet even in OECD countries would not qualify as computer–literate in any but the most rudimentary sense. As most governments in the world have the intention if not the capacity to offer publicly subsidised universal primary education, the answer to the question of why so many people remain illiterate must be sought elsewhere. Social institutions and culture no doubt play an important role, but one would expect that, if the private economic benefits of educating girls came to be widely recognised, institutional, cultural and political resistance would wither. This may indeed be happening in some societies, but apparently not in all. While it is premature to draw firm conclusions, it is possible that, in some poor countries at least, the diffusion of information and communications technologies throughout the economy would generate significant new demand for literate workers. In any case, the least educated, usually the poorest members of the workforce, are not likely to be the first to benefit from such demand (Panagariya, 2000)[13].

Intellectual Property Rights, Technology Access, and the Poor

One institution closely linked to technology development and diffusion is that of intellectual property protection. In the last decade and a half, developing countries have come under growing pressure from OECD countries to strengthen intellectual property rights (IPR) regimes. This is also required under the 1994 WTO Agreement on TRIPS[14]. Designing an appropriate legal framework for IPRs involves balancing two objectives: ensuring that adequate incentives are in place to encourage innovation, and ensuring that the fruits of innovation are widely accessible. While IPRs are not the only incentive to innovation, they are now the predominant one — at least for private–sector innovators — in OECD countries.

Developing–country governments have until recently resisted strong IPR protection, on the grounds that the costs are likely to exceed benefits for countries that are not major innovators but depend heavily on borrowed technology. As Maskus (2000) explains, there is a sound economic argument that optimal protection of intellectual property is an increasing function of income and technological capacity. With rising incomes people demand higher quality, differentiated goods, with trademarks and copyrights being a key aspect. At the same time, with an economy's growing technological sophistication, inventors are likely to demand greater protection for their works. In effect, globalisation has accelerated the whole process by exposing low–income countries to the IPR preferences of inventors in technologically advanced societies. In this case, unlike in some other areas of development economics, small country size may be a blessing, in that international companies are apt to be less inclined to press for strict enforcement in markets too small to matter to global profits.

There is a legitimate concern that poor people might not be able to afford highly beneficial R&D–based products — like new medicines — if companies are free (and choose) to incorporate full royalties into the price. An even more fundamental question concerns the direction of R&D efforts *vis–à–vis* the poor, who may simply not be an attractive enough market to justify development of technologies specifically tailored to their needs. Put simply, if the developers receive no IPR protection, they have no incentive to develop them, but if they do receive protection and charge accordingly, they have no market. Under the circumstances, perhaps the best that poor people can hope for from privately funded R&D is to benefit from technologies of broader applicability developed to serve a wider market, where there is a possibility of price discrimination between rich and poor countries (as for example with patented AIDS drugs). Alternatively, the public sector and private philanthropic foundations may be able to steer private R&D efforts toward poor people's health, nutritional, or other needs through innovative financing arrangements — like vaccine funds. Even then the amounts involved are likely to be small by comparison with self–generated private R&D funds, so this approach may be more effective in mobilising research efforts in universities than in private firms.

Biotechnology poses a particular set of IPR challenges. The first is the risk that the patenting of basic DNA sequences could hamper rather than foster the downstream development of useful biotechnology products by private or public research institutions. Because developing countries lag far behind in appropriation of patents for DNA sequences, they are especially vulnerable. Access to genomics databases and effective search software at reasonable cost are also crucial to biotechnology research institutions in developing countries. Developing countries also are concerned to share in any financial rewards deriving from research based on their indigenous genetic resources. In this connection, the increase in collaborative plant breeding and other collaborative research programmes involving farmers, their communities and research scientists raises new questions about recognition of collaborative innovation. These questions that may not be adequately addressed by either breeders' rights (which permit plant breeders to exclude others from commercialising material of a specific plant variety for 15–20 years) or the farmers' privilege (which leaves farmers free to use their own harvested material of protected varieties for the next production cycle on their own farms) (IDRC 2001). Developing countries may be able to negotiate contracts with international biotechnology companies, whereby the former gain access on favourable terms to biotechnology patents and genomic databases in exchange for the right of access to their germplasm and bioresources (de Janvry *et al.*, 1999).

Intimately related to the farmers' privilege is the question of how new bio–engineered plants reproduce and whether improved genetic traits would continue to be available to farmers beyond a single planting cycle. Work on terminator genes has had the objective of turning off those traits in plant offspring. Were that to become commonplace, the farmers' privilege would effectively be denied. The type of IPR protection afforded plant varieties is also crucial, since under patent law (as opposed to the *sui generis* legal regime of plant breeders' rights established by the International Union for the Protection of New Varieties of Plants, founded in 1961) on–farm seed saving of protected plant varieties may entail patent infringement (van Wijk *et al.* 1993).

In the domain of information and communications technologies, the main IPR issue is familiar: the risk of unauthorised copying of software and other information products. What is distinctive about this particular set of technologies is the economics, where potentially enormous fixed costs of software development combine with negligible costs of reproduction.

Maskus and Penubarti (1995, 1998) have estimated the effects of patent protection regimes on bilateral trade flows for a sample of 22 exporting countries (mostly OECD members) and 71 importing countries at all levels of development. They hypothesise two main ones. First, by increasing monopoly power of exporters, they could reduce the elasticity of import demand and cause a reduction in trade. Second, especially in large countries, they could make local imitation more costly and encourage an expansion of export market shares. Which of the two effects predominates? If the former, then, by the predictions of recent work on trade–related R&D spillovers (Coe and Helpman 1995; Coe *et al.* 1997), stronger patent protection could actually slow technology transfer and, in the process, domestic TFP growth. The authors find that, in the case of larger countries with strong technological capabilities, the market–expansion effect tends to predominate, because strong patent protection diminishes the credible threat of widespread imitation. By contrast, in poor countries with weak technological capabilities, the net effect of strong patent protection could be to reduce imports, since the market–power effect tends to outweigh any market–expansion incentive. Thus, for such countries, stronger patent protection could actually be counterproductive, reducing imports and perhaps thereby slowing TFP growth. In short, one size does not fit all.

Besides the IPR regime then, another set of policies, those affecting openness to trade and foreign investment, can have an important bearing on an economy's technological dynamism. Most developing countries depend on technology imported from more advanced countries and that technology usually enters through a combination of trade (technology embodied in imported capital equipment and intermediates) and foreign direct investment. Historically, trade barriers have operated to raise the costs of imports, including imported capital equipment. Connolly (1999) suggests that imported intermediates and capital goods can contribute to local technological advance in two ways: directly by improving process efficiency and product quality, and indirectly by allowing reverse engineering (learning to learn) to enhance future domestic R&D. Connolly raises the possibility that South–South regional trade agreements could, through trade diversion, substitute less technologically advanced imports from member developing countries for more advanced imports from non–member developed countries. It is hard to draw normative conclusions from this, since the less advanced technologies may be more suitable to local factor endowments and technological capabilities.

Final Thoughts on a Policy–Oriented Research Agenda

This review of literature and preliminary mapping of technology–poverty links point to a number of areas where further research is needed. The evidence from Ravallion *et al.* (various years) on *conditional* poverty reduction from non–farm output growth in India, while suggestive, leaves much unexplained. First, better understanding is needed of just what sorts of skill or other attributes lie behind the result that the initial human capital matters to a wider sharing of benefits from growth. Second, since most non–farm output is produced by either informal or formal enterprises, a better understanding is needed of how enterprise or sectoral characteristics may affect the incentives for technology upgrading. Does export orientation, for example, provide an inducement to technology acquisition? One would expect this to be the case in small countries at least, since any fixed cost involved could be spread over a larger output and higher export–market prices might also generate a higher return on such investment. Moreover, even if the introduction of new technology should be associated with a higher capital–output ratio, rapid expansion of the successful adopting firms could well more than compensate in terms of labour demand for any shrinkage of more labour–intensive and less competitive non–adopters. Again, it is the sector–wide, and ultimately the economy–wide, effects that are important in assessing impacts on the poor.

On agricultural biotechnology, Serageldin and Persley (2000) suggest two broad directions for future research to enhance benefits to poor people:

— *Contextualisation*: better understanding of complex farming systems in specific agro–ecological regions with a view to ensuring that new technologies are a) environmentally sustainable and b) well adapted to the social context of expected introduction.

— *Refocusing*: to exploit the potential of biotechnology to address the specific needs of poor farmers and poor consumers. This raises the question of what combination of public policy and private institutions can act as an effective “focusing device” (in Rosenberg’s phrase) on the problems of the poor.

The likely long–run impact of information and communications technology on poverty remains speculative. The research need in this area is to move beyond anecdotes to the formulation and testing of hypotheses about the precise ways in which these technologies are likely to affect the poor. One such approach has been outlined here, using a simple general equilibrium simulation model. Econometric analyses suffer from the problem of a relatively short history of technology use, especially in developing countries; by default, any such analyses would have to be largely cross–sectional, with all the pitfalls that involves in this context. Time series estimates of the growth impacts of earlier communications technologies — mainly the telephone — are available, but they have focused almost exclusively on aggregate growth impacts.

The half of Lipton's virtuous circle running from poverty reduction to technical change also warrants further investigation. Craig *et al.* (1997) find that life expectancy has a larger and more significant impact on labour productivity in agriculture than commercial fertiliser use, tractor horsepower, and research expenditures. While it is possible that investments in health would have a bigger productivity payoff than agricultural input subsidies, the authors note that confirmation of this awaits better measures of human and physical capital inputs.

The design of intellectual property regimes suitable to developing country agriculture would benefit from research on costs and benefits. Blakeney *et al.* (1999) note that "virtually no empirical analyses, either sociological or economic, have been done on the impact of IPR on food and agriculture, especially in developing countries" (p. 225). At the same time, the authors acknowledge the difficulty of undertaking such research, especially in the short time frame for bringing national IPR policies into conformity with requirements of international agreements like TRIPS.

Notes

1. Thanks go to Andrea Goldstein for comments on an earlier draft and to Michael Lipton, who provided valuable feedback as discussant. The usual disclaimer applies.

2. One explanation of Solow's "productivity paradox" is that it takes time for organisations (specifically, firms) to adapt to the requirements of effective use of a new technological innovation — in this case, the computer (Bresnahan, 1997).

3. One might make the case that modern medicine and pharmaceuticals rival agricultural technologies in importance to the quality of life of poor people. Be that as it may, the focus here is on the latter, although to a degree the issues of *i)* how to encourage greater expenditure of R&D effort on the problems of the poor, and *ii)* how to make the technologies accessible to the poor, are common to the two sets of technologies.

4. See Helpman (1998) for a thorough theoretical and empirical discussion of GPTs.

5. While within-country Ginis may not vary much over time, even small variations can make a big difference in how much the poor share in growth.

6. Once a given technology is adopted, however, further productivity improvement mostly involves learning-by-doing, for which experience is more important than formal schooling.

7. The International Rice Research Institute (IRRI) has pioneered development of HYVs of rice and given its initials to the major green revolution rice varieties grown in Asia.

8. See David (2000) for a cautionary note on the implications of the March 1996 EU European Database Directive for open, collaborative scientific research, which threatens an "overfencing of the public knowledge commons" to the detriment of poor countries.

9. A few fundamental contributions can be found in: Coase (1937), Williamson (1975, 1985) and Wallis and North (1986). For a recent survey see Williamson (2000).

10. Kurz (1974), Hahn (1971), Foley (1970).

11. These data were obtained from a Social Accounting Matrix estimated by Pradhan *et al.* 1999. More details are available upon request.

12. Biotechnology holds promise in this domain, since DNA-based vaccines remain stable without refrigeration or special handling requirements.

13. See also Quibria and Tschang (2000), who find a strong positive relationship in a cross-country regression between internet and personal computer use on the one hand and tertiary education on the other, but no such relationship with primary education.

14. TRIPS, the Agreement on Trade-Related Aspects of Intellectual Property Rights, gives protection to many forms of intellectual property (copyright, trademarks, service marks, geographical indicators, industrial designs, patents, trade secrets, etc.), requiring that appropriate legal avenues of recourse are available when infringement is alleged to have occurred, and ensuring any resulting dispute is resolved in the same manner as other trade disputes (KPMG, 2000). The TRIPS Agreement requires all signatory countries to provide at least a *sui generis* system of protection for plant varieties (Serageldin and Persley, 2000).

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