Journal of Development Studies,
Vol. 43, No. 1, 31–62, January 2007

Routledge
Taylor & Francis Group

Plant Breeding and Poverty: Can Transgenic Seeds Replicate the 'Green Revolution' as a Source of Gains for the Poor?[1]

MICHAEL LIPTON
Poverty Research Unit, Sussex University, UK

ABSTRACT *Improved farm technology helps all main groups of the poor – small farmers, farmworkers, other low-wage labour – when it raises labour value-productivity, but raises land and/or water value-productivity faster; and cuts staples prices, but raises smallholders' total factor productivity faster. From 1965 the Green Revolution walked these two tightropes largely by luck. Though targeting bigger piles of rice and wheat, it cut poverty through consumption; nutrition; smallholder income; employment; risk reduction; and ecological sustainability. Yet large areas were left out, and from 1985 progress slowed. In the new environment for research and agriculture, how can transgenics revive and spread poverty reduction? What has been the evidence so far? What determines whether new varieties have traits conducive to poverty reduction: who owns the research, or what crop science is?*

I. Introduction

Most of the world's poor depend mainly in farming for their income. Most poor farmers cannot readily farm more land, or obtain more water. Yet the farm population is still growing, and the farm workforce is growing faster. In such circumstances, the conditions for an improved farm technology to benefit all major groups of the working poor[2] – those earning income mainly from farming, farm labour, and non-farm rural and urban labour – are tight. The improved farm technology must 'walk two tightropes' (Lipton, 2005: 11). It must:

- Raise labour productivity, so poor farmers get more reward for effort; *but*
- Raise land and water productivity *faster*, so employment, on unchanged land and water, rises.
- Cut staples prices through increased output (so the non-farm poor gain); *but*
- Raise total factor productivity (conversion of inputs to outputs) *faster*, so poor farmers gain.

Correspondence Address: 15 Eaton Place, Brighton BN2 1EH, UK.

ISSN 0022-0388 Print/1743-9140 Online/07/010031-32
DOI: 10.1080/00220380601055510

Section II traces six main routes from GR (or GM) to poverty change: via consumption; nutrition; cereals production; employment income; risk; and sustainability. For each route, we confirm that the GR tended to reduce poverty, and ask what this suggests for GM. Section III enquires why the GR, though aimed at raising food supply, also raised the poor's income and food entitlements; why it missed many areas; and why its impact has slowed – and explores whether, in a changed situation, GM might help. Has the agricultural, demographic or nutritional environment changed between GR and GM, in ways affecting the poverty impact of improved seeds? Does change (e.g., privatisation) in supply, demand and 'industrial structure' of seed research between GR and GM mean changed poverty outcomes? Or is science – its continuity or exogenous change – more important? Section IV sketches some evidence about GM and poverty reduction so far. Section V explores issues for GM, arising from earlier conclusions.

A key issue turns out to be: what mainly determines whether new seeds have the features most conducive to poverty reduction, 'property' or 'science'? If it is mainly whether research *institutions and outputs* are in the public-purpose sector (as with the GR), then, for GM seeds – researched and sold mostly by private companies – to help the poor more than incidentally may depend on new public-purpose incentives to private GM research, e.g., a shift from royalties to contracts. If the poverty impact of modern seed research – GR or GM – is mainly driven by the options opened (or closed) by the basic science, then what matters most is that GM both widens and sharpens GR's tendency to seek *broad-range* changes in plant architecture or chemistry. Genes, with identified effects transferred to one GM crop, may produce similar effects in others. Hence GM advances, developed for crops of main interest to rich farmers and consumers, may prove applicable to other crops, eaten or grown mainly by the poor. Further, transgenics offers hope of yield enhancement for crops whose pre-GM field varieties were selected, by farmers, less for yield than for survival in ill-watered, high-risk environments (where the poor mainly live and work (IFPRI 2001)) – in Africa, sorghum, millet, and root and tuber crops.

Major gains from GM crops for the world's dollar-poor[3] require staple-crop research focus on yield, water-efficiency and robustness, via employment enhancement. Details depend on initial situations (changed by GR) and local agro-ecologies; methods depend partly on whether science or property is the main driver of GM research focus. These issues have not been much addressed. So we question most claims that gains for the poorest from GM are very close. However, exceptions (Section IV) suggest potential medium-term (10–30 year) poverty reduction from GM comparable with that in the GR – with attainable changes, not just in research institutions and incentives, but in scientific and economic criteria within GM research.

II. From Higher Yields to Less Poverty? Lessons From Six Paths in the Green Revolution

The GR is the spread of radically improved non-transgenic[4] staples in developing countries. The new plant types were maize hybrids from the mid-1950s and rice and wheat semi-dwarfs from the early 1960s. These have spread across high proportions of cropland in Asia and Latin America, and small but significant proportions in Africa. The new varieties, from the start, were much more fertiliser-responsive and better yielding than the old, in areas with good water control and pest management. From about 1970, new varieties focused on resisting successive pest biotypes, and on less secure soil-water environments. They were mostly initiated in the international public sector, and crossed for local use by public-sector national research. The GR more than doubled food supply in Asia in 25 years, with an increase of only 4 per cent in net cropped area (Rosegrant and Hazell, 1999). The main routes from the GR to poverty change were through consumption; nutrition; cereals production; labour income through employment; risk; and ecological sustainability (Lipton with Longhurst, 1989; Kerr and Kohlavalli, 1999; Hazell et al., 2000).

Consumption

The GR raised staples output and therefore restrained prices. It raised output most where wheat or rice was grown with adequate, controlled water. Extra output restrained prices most in big, protected countries, where international trade had little effect on prices. Both applied in huge economies – Bangladesh, Brazil, China, India, Indonesia, Mexico, Pakistan – where before the GR the dollar-poor were massively concentrated. Hence poverty fell sharply in 1970–90: most sharply when, and where, the GR was raising staples yields fastest.

Staple food consumption typically uses 45–70 per cent of income for the dollar-poor, much more than for others. So staples price restraint, due to the GR, helped the poor much more than the rich. On the consumption side, the GR was not only pro-poor but also redistributive. Even in Latin America, where land inequality limited the poor's gains as farmers, this consumption effect reduced poverty (Pinstrup-Andersen et al., 1976). For GM similarly to cut poverty via consumption requires much more focus on enhancing staples, yields and robustness.

Nutrition

The poor are the most harmed by protein-energy malnutrition. Almost always, ending calorie deficiency is the best route to protein adequacy. Hence GR or transgenics best attacks malnutrition by raising staples yield, and thus calories, per hectare and per litre,[5] on small farms and employment-intensively (that is, so the poor get more income and can afford more calories).[6]

However, by focusing on calories, GR bypassed widespread, serious shortfalls in iron, zinc, and vitamin A. Dietary diversification is a long-run solution; now, many dollar-poor cannot afford this *and* sufficient staples. Given the huge damage due to deficient bio-absorbable micronutrients (FAO, 2000), can one increase them in key staples? Further, iron, zinc and vitamin A deficiencies probably worsen the nutritional harm from a given calorie inadequacy. The new prospects opened by transgenics for micronutrient staples breeding are treated in the contribution of Howarth Bouis (2007). Micronutrients apart, the nutritional issue facing transgenics (as was the case for GR) is: will it raise food entitlements for the malnourished?

Production

In Asia, one would expect production effects of the GR on rural poverty, by way of small farmers, to loom larger than in Latin America, compared with consumption effects. A much larger proportion of cropland in Asia is in smallholdings. In Asian GR areas – though at first poor adopters faced severe problems of access and management – from the late 1960s smaller and poorer farmers used GR innovations, *where they were adopted*, as widely, and at least as intensively, as other farmers (Hossain, 1988; Lipton with Longhurst, 1989).

GR greatly helped poor staples farmers where it worked, but in non-GR areas created problems for them. If 'stuck' in staples production and immobile, the GR brought them no higher productivity, but a lower output price. Indeed, rural areas of India with least GR-based productivity growth around 1965–85 also had least poverty reduction. Yet four factors helped *some* poor farmers in *some* non-GR areas. Poverty impact of transgenics in these areas – usually the poorest – will improve if scientists and economists review these four 'lessons from GR' before prioritising traits, target regions, and research lines.

First, many poor farmers outside GR zones were net buyers of food staples and thus gained from lower prices. Second, some areas without a GR in cereals were able to shift land profitably into crops such as sugar, mustard and cotton that had been abandoned in areas benefiting from the huge cereals productivity improvements of the GR (Hazell and Ramasamy, 1991). Third, many non-target areas benefited from GR varieties. For example, second-generation and later rice and wheat semi-dwarfs spread widely in South Asia even where they brought little yield gain, due to their increased robustness (Lipton with Longhurst, 1989). In India, it was in these later stages of GR that its poverty reduction impact was greatest (Smith and Urey, 2002). Fourth, in India and China, returns to seed research are now higher in some supposedly non-GR areas than in the classical GR lead areas (Fan et al., 2000; 2000a).

The message from GR to transgenics is that, for poor farmers outside initial target areas to gain from new seeds, research policy response is key. Sri Lanka's came early in the GR, switching rice breeders' emphasis from the Dry Zone to the lagging Wet Zone around 1975. India and China implemented similar shifts later. Faster poverty reduction followed. In African countries with less explicit research policies, improved varieties were little help to poor farmers outside target areas.

What happened to farmers, often the poorest, growing staples less affected by the GR: millet, maize, sorghum, cassava? They lost as sellers; GR, by making rice and wheat cheaper, also cut the price of competing staples. They derived modest offsetting productivity gains for millet and sorghum in Asia, but far less in Africa (Lipton, 1994). What will transgenics do for such farmers? Will it be profitable to research, say, transgenic millet? The contrasts between the GR in Africa and Asia suggest that good, carefully prioritised *national* adaptive breeding is crucial, if transgenics is to help poor farmers stuck in 'backward' crops or areas.

Employment and Wage Income

In rural India in 1999–2000, one-third each of households had farming and farm labour as main income source. Of farmers, 24 per cent were below the national poverty line; of farm labour households, 47 per cent.[7] In India, and almost certainly much of South Asia, Latin America and Southern Africa, ratios of poor farm labourers to poor farmers are steadily increasing. So the poverty effects of GR, and even more transgenics, may operate by way of impact on farmworkers (through wage-rates and employment) more than on farmers (through output and price).

Ensuring transgenic varieties are suitable for small farmers helps poor labourers too. Small farms use more labour per hectare than large farms – even, usually, more *hired* labour. Also, as new varieties – GR or transgenics – make *family* labour more rewarding, small farmers work more on the home farm, leaving the hired labour market to poorer near-landless labour.

However, while the GR raised rice and wheat yields – and hence employment – tractors and weedicides reduced employment. Staples employment rose about 40 per cent as fast as yields in the early 1970s, but only 15 per cent as fast in the mid-1980s, and perhaps less now.[8] The fall is partly due to labour-saving bias in new varieties, for example, their being designed increasingly to accommodate combines or herbicides, or to suit larger, less labour-intensive farms. The fall is not always bad news for poor workers.

(a) In some areas, for example, Malaysia, it happened because labourers were doing well; labour displacement by new GR varieties responded to their increasing scarcity and higher wage.
(b) Where farmland is 'very equal' (for example, much of China), almost all the rural poor *choose* whether they wish to save labour (largely their own) by using such varieties.
(c) Where there is decent unused land (parts of West Africa), the poor can break it in, if they can save labour on their existing holdings.
(d) However, falling employment content of farm output – aggravated by glyphosate-resistant crops, for example – *is* bad for the growing majority of rural poor who rely on farm labour more than farming, where farmland is unequal and extra farmland scarce: in most of Latin America and Southern Africa, and much of South Asia. There, poverty is best reduced by steering transgenics research towards labour-intensive uses and farms.

Overall policy, not just breeding strategy, affects the poverty impact of GR or transgenics. Policy makers have 'agency', and can turn almost any breeding strategy in favour of – or against – the rural poor. If policy *shifts* sharply towards getting them more land, the poor may even come to gain from labour-saving varieties that reduce their effort, especially if they can use it to earn outside farming.[9] However, it is seldom realistic for breeders to tell policymakers: redistribute land, so our labour-saving varieties will benefit the poor. Breeders' and funders' 'agency' – crop and trait choice in research objectives – is therefore a key influence on poverty.

Our ignorance of the effects on labour-demand, and hence labour poverty, of alternative strategies for plant breeding, and for agricultural research more generally, is a gap in our understanding of both GR and transgenics impact. Also, such impact on *total* employment income[10] can differ from impact on *local staples* employment income. Public-purpose research can 'learn' to respond. For example, IRRI shifted from initial focus on maximal-yield but risky varieties such as IR-8, requiring high inputs and management and best suited to big farmers, towards more robust varieties such as IR-20. *For a private researcher, cutting unit costs of labour is* *as valid an aim as cutting any other type of unit cost. From a social viewpoint, that is false in a poverty-ridden world.*

Risk

The very early GR varieties were more management- and water-sensitive than older staples varieties, and therefore were seen in the 1960s as increasing farmers' income risk. New GR varieties increasingly aimed to reduce *farm-level risk*. After the first thrust of yield enhancement through semi-dwarfing, successive varieties steadily sought improved resistance to a widening range of pests and pest biotypes. This partly explains the spread of GR varieties in Asia to areas where their yield impact was small.

It is less clear that the GR reduced *consumption variability*. Rising staples production variability accompanied the GR in some countries for some 15 years.[11] In India, where national staples consumption is mainly from domestic production, that increased consumption instability. For most Indians, GR nevertheless cut *nutritional risk*; a greater likelihood of a 5 per cent fall below mean calorie intake was outweighed because GR had also raised that mean, so a 5 per cent shortfall did less harm. However, for Indians who did not raise mean consumption (for example, because they worked in non-GR areas), more variable consumption meant more nutritional risk. This danger is now less; since the mid 1980s, new varieties have increasingly *defended* yields against higher variability, rather than maximising them in lead areas. A more serious variability issue is ironically due to the excellence of individual GR varieties, which become dominant over a wide area; if a new pest biotype 'likes' something about a dominant variety,[12] widespread disaster can result. In those cases, skill, speed and luck led to a resistant replacement variety very soon. Until this happens – or if it fails – it is the poorest who suffer most.

Agriculture, however, is a natural enemy of biodiversity: profitable crops and varieties drive out others through farmer choice. Formal research systems tend to make matters 'worse', because they tend to seek varieties offering, over large areas, dramatic rises in yield, and short-term immunity to pest attack: good varieties drive out bad, and that's bad.[13] The GR has been an extreme case: especially for rice, where almost all GR varieties depend on a single dwarfing gene, further selection for multiple pest resistances often means that, over quite large areas, even distinct varieties are genetically close. But we should not assume that breeders ignore this obvious point. They attempt, with some success, to preserve biodiversity, through varietal collections and to some extent in situ. However, there are limits. SE Asian rice in the field is disturbingly un-diverse genetically.

Transgenics, contrary to its reputation, promises substantial increases in field biodiversity. The John Innes Institute has introduced a new dwarfing gene into rice.[14] If rice varieties incorporating it are developed, field-tested and widely adopted, they will add diversity to the rice varieties available. More generally, transgenics increases both the precision and the crop range of gene insertions. To oppose transgenics is not to *defend* biodiversity (with its concomitant long-run reduction of pest-disaster risk), but to *attack* a possible path to biodiversity which one dislikes on other grounds.[15]

The privatisation of much varietal improvement – absent public-purpose incentives to private breeders – may bias, in an anti-poor way, some of the ways in which transgenics approaches risk. For instance, transgenic *Bt* insect resistance slashes, for now, risk from bollworm or corn borer in 'surge' years for those pests. But the resistance is single-gene, or (in some varieties) from two genes expressing similar proteins. If a new pest biotype overcomes the resistant gene, the rich can access and afford pesticide, but the poor may not be able to do so. They therefore prefer horizontal (polygene), moderate resistance or tolerance to biotic stresses. This is well suited (though difficult) for transgenics, but unattractive to breeders whose incentive is to serve large, not very risk-averse farmers.

Ecological Sustainability

The poorest can do least to pre-empt environmental degradation, yet are most harmed – having fewest viable options – once it degrades their land-soil-water systems below some threshold. Many people believe that (a) sustainability of land-soil-water systems is threatened by the shift from traditional, low-input, 'organic', or localised farming to modern, intensive, pesticide/inorganics-heavy, or commercialised (globalised, homogenised) agriculture; (b) the GR, and especially transgenics crops, are an inextricable part of that threat. Some of the appurtenances of modern farming are unaesthetic and arguably, or potentially, unhealthy. However, plant breeding is a tool – of companies, states or societies – not an inherent part of an overall agricultural trend. This paper claims that:

(a) Agricultural intensification *in a world of overall population and income growth* is more environment-preserving than the alternative, extension of farm area.
(b) Plant breeding, if directed responsively to scientific and public[16] concerns, is more environment-preserving than alternative means of intensification, such as more pesticide use.
(c) The GR illustrates these facts, though it meant more use of fertiliser (and, more gravely, water).
(d) Transgenics can enhance the environment-preserving aspects of plant breeding.

(a) Agricultural intensification. Population growth leads to roughly proportionate growth, other things equal, in demand for staples and other farm products. Income-per-person growth leads to less than proportionate growth in demand for staples, but (approximately balancing this) more-than-proportionate growth in demand for animal products, which typically use three to six times more staples per calorie available to humans. Hence 'stylised reality' in 1950–2000 – world population growth and income-per-head growth each at 2 per cent yearly – requires, to match expanding demand without dearer food, a *7.2-fold* rise in staples output. With little good unused cropland, the options are: expand cropping into increasingly unviable marginal lands; or accelerate yields through intensification. In fact, world staples growth *outpaced* demand growth. In 1950–2000, the GR helped push up staples yields fast enough for real prices to fall *and*, GR regions, for staples-based employment income to rise. That allowed unprecedented poverty reduction, without 'help' from cropped-area expansion that degraded marginal lands elsewhere, especially in Africa. Also, the GR

slowed sharply from 1985, leaving much of Africa, and ill-watered parts of Asia, little affected. These times and places also saw faster degradation of marginal lands and/or slower poverty reduction. Though population growth will be slower in coming decades than in 1950–2000, consumption of animal products – and hence demand for feedgrains – is rising faster (because incomes are higher); and workforce growth remains around 2 per cent yearly. How, without further massive degradation of marginal lands,[17] can the required extra food *and* 'entitlements' for the poor (through employment income) be provided? Clearly, further big staples yield increases are needed. Extra workplaces are most cheaply generated in rural areas, and are most cost-effective in improving food intakes if they make local calories cheaper and more. Worsening water shortages and unreliability, bearing most harshly on the poor (International Fund for Agricultural Development [IFAD], 2001: 94–7), increase the obstacles to cropped area expansion, and the need for more 'crop per drop' – as well as more resistance to moisture stress – alongside higher yields.

(b) Plant breeding. To restore and spread growth in staples yields, a major new impetus is required. The staples yield growth trend in developing countries, around 3 per cent in 1975–85, has steadily fallen to about 1 per cent now. More fertilisers can revive the trend, but without substantial improvement in germplasm they have diminishing returns; higher applications are economically unattractive at current prices in the poverty heartlands: much of Africa, West China and East–Central India. Progress requires, in some areas, more irrigation, and almost everywhere better progress in plant breeding. Conventional breeding has rightly and increasingly become 'defensive', seeking yield *maintenance* in face of new pest biotypes and water depletion: hence slower yield *enhancement*.

(c) The GR. The GR illustrates the environmental prospects – but also the traps, and the need for economic analysis – in transgenics policy construction. Both GR and transgenics normally raise output per litre, per extra unit of water, fertiliser and pesticide; how will this affect the use of these resources? Successive new pest-resistant varieties have almost certainly reduced pesticide use per ton of output. However, GR varieties greatly raised the marginal product of nitrogenous fertiliser around its pre-GR use levels, and hence its use. In water-scarce wheat areas, it did the same for water. These incentives led to severe water depletion – sinking water-tables, overused surface-water systems – and some nitrate and nitrite pollution of drinking-water sources, in many parts of India. The environmental damage from achieving comparable output increases through area expansion would have been far more; but varietal and other input choices in research can and should be predicted and planned to improve environmental impact.

(d) Transgenics. Transgenics – even in its deeply flawed manifestations and commercial origins so far, and much more so potentially – illustrates the environment-preserving role of plant breeding, under conditions discussed below. Alongside new water science, functional crop genomics and transgenics must be part of any solution to the water crisis of farming, complementary to the water reforms more widely advocated (World Water Council, 2000).

III. Green Revolution Puzzles and Transgenics-Era Parallels

To explore the scope, limits and prospects of transgenics in reviving and spreading poverty reduction, we ask four questions.

(a) Why was the GR – while and where it happened – so good at reducing poverty?
(b) Why were there big regional gaps, and a sharp slowdown, in the GR – and can transgenics help?
(c) Has the poverty impact of staples seed improvement been affected by major change, from GR to transgenics eras, in 'demand' for seed research?
(d) As for changes in 'supply' side of such research, does poverty impact of new seeds depend more on change in the 'industrial structure' of seed research, or on change (or continuity) in the science?

How did GR, with no 'Food Entitlements' Agenda, Slash Poverty and Undernutrition?

A now-classic 1959 study diagnosed the need for yield-enhancing strategies, as prospects to expand cropped area dwindled (*India's foodgrain crisis*, 1959). An emergency was signalled by India's near-famines in 1965–66 and China's in 1960–63. The GR seemed a credible response to emergency, seeking to raise staples *availability* by enhancing yields of the most promising crops (rice and wheat), initially on reliably irrigated land, for larger farmers, in institutionally better-served areas.

Now, however, we know (Sen, 1981) that low or reduced food *entitlements*, not availability, cause most famine and hunger. They exist in a world, countries, and even small areas that – even in bad years – grow more than enough to provide ample calories for all. If the designers of GR overestimated the role of increased local food *production and availability* in overcoming hunger, and underestimated the role of increased *entitlements* to food, why did the GR do so well in cutting poverty? The answer is partly luck; the lesson for transgenics is threefold.

- The GR, where it happened, raised staples availability in most countries in ways that also raised food entitlements. This involved walking two tightropes. In GR areas, it raised total factor productivity (so poor farmers gained) *faster* than it lowered the price of staples output (so poor consumers gained). And the GR raised the average and marginal products of labour (so employed workers got more income per hour), but in land- and/or water-scarce areas it raised the average and marginal products of land and/or water *faster* (so farm unemployment fell) (Lipton, 2005).
- Where the poor at first gained little or lost, the (public-purpose) institutions and (science-based) incentives of most GR research made it responsive to criticism (for example, the shifts of breeding priorities towards robust varieties and neglected regions). Private research lacks pro-poor incentives.
- The science underlying GR and transgenics alike – as adapted and applied by farmers where there is abundant labour – may, however, bring innovations that 'walk the tightropes' above.

The greater the extent to which the internal organisation of research (rather than the nature of modern seed research however it is done) was the main reason why the GR so successfully raised staples *entitlements* of the poor, the more radical is the change needed to make transgenics structure and organisation produce results as pro-poor as the GR's generally were.

Why the Gaps and the Slowdown in the GR – and is Transgenics Well Placed to Help?

Gaps. High-yielding GR rice and wheat semi-dwarfs and maize hybrids cover more than 80 per cent of areas sown to these crops in South, East and West Asia and North Africa; over 70 per cent in Latin America; but below one-third in Sub-Saharan Africa. Despite major efforts in leading developing-country and international research institutes, offtake was weak in uplands and unreliably watered lowlands. Also, yield gains in farmers' fields from varieties embodying GR approaches were much smaller, and spread more slowly, for sorghum, millet, cassava and yams – alongside maize, the main staples grown and eaten by Africa's poor.

The gaps are due partly to national policy priorities constraining, for example, local research and fertiliser use, but mainly to limited prospects for applying the GR concept to the unaffected areas. National policy is in part a response to such limitations: why spend scarce resources on GR research, if you believe it will achieve little in your country? The three main limitations are (a) scanty or uncontrolled farm water; (b) few, or badly-absorbed, plant nutrients from fertiliser; (c) a crop-mix locked into low-value staples that are selected (by nature and by farmers) for hardiness, not high yields.

The three features are linked. If water is unreliable, returns to fertiliser are lower and less secure, and farmers are driven to prefer hardy, lower-input staples. Yet the features also have exogenous causes. The recency of land scarcity in parts of Sub-Saharan Africa has delayed incentives, to governments as well as farmers, to recognise a need for intensification, and hence for better water control and nutrient supplementation.

Water-control issues will have to be faced, before GR-type varieties can make a large and rapid impact in Sub-Saharan Africa, and probably also in many little-affected areas in Asia. Gross irrigated area comprised 1.5–3.8 per cent of gross land cropped in Sub-Saharan Africa in 2000, compared with 49 per cent in Bangladesh, 37 per cent in China, 32 per cent in India, 14 per cent in Indonesia, 23 per cent in Mexico and 82 per cent in Pakistan.[18] It is on water-controlled land that GR varieties have transformed staples yields.

However, while plant breeding cannot now raise yields at 'Punjab rates' in unirrigated semi-arid or upland farming, transgenics may make a big difference. If the genetic mix of field varieties of main African staples is adapted to good performance when water is scarce, then DNA from other crops may be needed to generate new varieties offering substantially higher yields without unacceptable water risk. For example, conventional plant breeding has had little success either in raising African millet yields, or in introducing latency, especially at the time of anther formation, into maize. Many farmers grow low-yield millets or maize landraces, rejecting high-yielding maize hybrids because they are believed to raise unacceptably the risk of crop failure if the rains start late. Transgenics may be necessary and sufficient to introduce latency into high-yielding maize varieties – or dramatically higher yield into millet – across species barriers. There are, as always, efforts in the pipeline,[19] but if company profits are driven by royalties rather than contracts, their focus is bound to be, as usual, on breeding for soil-water conditions of large, mainly North American, farmers from whom royalties are readily recoverable.[20]

Water scarcity or unreliability constrains fertiliser use.[21] Together, in many areas they constrain returns from conventionally bred varieties, and shift farmers towards crops where the GR has achieved less. Transgenics probably has the *potential* to transform yields in the latter crops, and to make standard GR crops less prone to moisture stress (Nuffield, 2004: 3.42). To slash poverty in some recalcitrant non-GR areas, they ultimately must get water control or quit agriculture – just as nutrient deficiency must ultimately be tackled by diversified diets. But meanwhile the poor must live, and transgenics offers hope. The case for more irrigation, major as well as minor, in Africa is stronger than often claimed (IFAD 2001), but it will be a long haul, offset by the shift of water to domestic uses, and by faster evaporation due to global warming. Until the long haul is well under way, the gaps in the GR – and the overlapping gaps in rural poverty reduction – will not be addressed unless transgenics turns towards enabling higher yields *in the conditions of poor rural areas* despite scarce or unreliable water.

Slowdown. The growth of staples yields in developing countries in the 1990s was about a third as fast as in the 1970s (Lipton, 2000). Combined with the falling responsiveness of farm employment to yield growth, the growth downtrend has made rural poverty reduction harder. The downtrend has several causes, but fundamental is the falling GR contribution. Can transgenics attack its causes?

The GR's falling effect in yield growth partly reflects its success. GR varieties first spread through the best-suited areas; if similar varieties spread to less well-suited areas, yield impact falls. Transgenics could address this, if gene insertions could do things, infeasible within a crop's genome, to make it less sensitive to the abiotic constraints that create 'less-favoured areas'. On matters such as drought resistance, there are proof-of-concept examples (Nuffield, 1999: 2.49; 2004: 3.42), but incentives to develop them are reduced by another cause of yield slowdown. That is the shift, with transgenics and otherwise, of agricultural research resources towards the private system. Companies have other priorities than reaching small, dispersed, poor farmers, especially with self-pollinating crops. Further, even within the public system, resources have shifted sharply away from crop productivity enhancement, towards environmental and policy research (Lipton, 2000). Perhaps above all, even the depleted public-sector research on crop productivity has been forced (by ever-changing pest biotypes, falling water-tables and soil micronutrient depletion) to shift from yield enhancement to yield maintenance, that is, to become increasingly defensive.[22]

Are there funds to develop such transgenic seeds for profitable small-farmer use? There are currently two impediments. First is the cost of clearing regulatory hurdles, arbitrarily imposed on just one sub-class of new seeds (transgenics) that is no more, and probably less, risky for health or environment than other sub-classes. Second is the reluctance of funders to divert resources from seed development or poverty reduction to a tiring, boring struggle against pseudo-environmentalist PR and scientific ignorance.

Great inventions – such as new techniques of plant dwarfing to raise yield through a higher harvest index and reduced lodging – produce a 'watershed' of applied innovation and adoption. The flow inevitably peaks and then declines, unless the source is replenished through new inventions. Despite important advances in conventional breeding, transgenics seems the only substantial new source to re-start the GR process of rapid poverty reduction, but only if changed public resources and private incentives greatly change the current directions of transgenics research.

Changes in Farming, Nutrition, and Demography

Both demand for staples research and the poor's need for its products depend on farming, nutrition and demography. All have changed between 1955–70 and 1995–2010, the formative years for GR and transgenics research respectively. Does that alter the impact of research decisions on the poor?

Changes in farming. In low-income countries, staples demand continues to be increased by rising population, income per person, and staples requirements per calorie as diets switched to animal products.[23] However, incentives to farmers and researchers behaved contrarily. Support to rich-country farmers surged,[24] while repression of farm prices and production in poor countries declined. Both these trends have increasingly glutted farm markets, four main considerations are relevant.

First, to maintain developing-country farmers' competitiveness, research has to cut their unit costs faster than the GR did – but with a more degraded land-water environment: 'to produce a doubly green revolution at half the price' (Maxwell, 2004). Adopting transgenics further raises market supply and cuts price. This will make farming in countries that reject transgenics ever more uncompetitive[25] – presaging futile[26] efforts to create a world 'half-transgenic and half-nontransgenic'. These price effects are mitigated if transgenics research to raise staples output is focused on people who tend to eat it themselves: small farmers, their employees, and poor areas.

Second, perversely, the focus tends to be on big and rich farms, where demand for farm products is being transformed by new institutions of globalisation: supermarkets, public and private product grades and standards, and export horticulture (Reardon et al., 2003). This transformation is fast and far advanced in some developing areas (Latin America, SE Asia, Southern Africa). Where there is 'intermediation failure' between the new institutions and small farmers, their cash-cropping may well become unviable. These 'unmediated' poor will focus more on staples production, and will place distinct demands on transgenics for crop-mix and traits.

Third, the poor's need for sustainable income sources is much more threatened by water shortage than in the GR's formative years. The GR raised crop-per-drop, but thereby also incentives to water use; on balance, demand for water rose. Further, associated higher fertiliser use reduced the recyclability of farm water. Transgenics has potential to raise crop-per-drop further, but only if 'steered' to identify, test and spread the complex multi-gene insertions probably required.

Fourth, public-sector capacity to meet the poor's needs from agriculture has been undermined since GR days by the collapse of aid to the sector. It fell sharply in the 1980s, and again by 65 per cent in real terms in 1988–98 (IFAD, 2001: 41).

Deteriorating farm infrastructure (irrigation, roads) requires revived investment, including aid, to benefit from transgenics and other research.

Small farms are smaller, yet more productive, than in the GR era. They face new, and differently distorted, environments, governments, institutions and incentives. So do the researchers who seek to serve these farmers. Planning for transgenics research needs to be aware of how these things affect specific local farm contexts. Hence agricultural economists and other social sciences need far more direct linkage with natural scientists in research planning.

Nutrition. The GR helped East Asia and Latin America to slash protein-energy malnutrition, which remains widespread in Sub-Saharan Africa, where it has not lessened, and South Asia. In those areas, it remains the first public-purpose goal of breeding to raise the poor's command over calories.[27]

The GR's partial success against undernutrition has exposed a second problem: micronutrient deficiencies. Conventional plant breeding here has limits. Bioabsorbable iron sources in rice can be increased successfully by conventional breeding; but only transgenics can introduce provitamin A into the endosperm of rice. Nutritional 'diseases of affluence' (obesity, coronary heart disease, diabetes) increasingly plague poor countries. The needs of the poor from transgenics are relevant. Child *under*nutrition increases exposure to diseases of affluence,[28] that is, of adult *over*nutrition, just as child obesity does. All can be tackled with growing, parallel understanding of human and plant functional genomics. This may permit a transgenic transition from 'diseases of poverty' to greater wellness.

Transgenics and the new demographics. Developing countries' rapid growth rates of population in the 1960s have slowed substantially, even in sub-Saharan Africa. Working-age population, however, is still growing at over 2 per cent annually in much of the developing world. So the workforce/dependant ratio, as compared with 1960–90, is rising much faster in 2000–30. In 2000, there were 101 people of prime working age for every 100 dependants in Ethiopia; the projection for 2030 is 139. For Nigeria the rise is from 101 to 150; for Bangladesh from 126 to 181; for India from 140 to 172 (UN [ECOSOC], 2005). After 2030–50, ageing populations start to reverse these gains. So the next thirty years form a 'window of opportunity' – and danger – for poverty reduction. Will more workers and savers, with fewer extra dependants, slash poverty – or employment and wage-rates? The choice depends heavily on whether staples breeding strategy creates enough productive workplaces.[29]

Agricultural, nutritional and demographic differences between the early GR and early transgenics eras may transform (a) how seed researchers' strategy affects poverty, (b) what they can do if they prioritise poverty reduction. GR evidence indicates that fast technical progress for small-scale and/or employment-intensive farms seems necessary and sufficient to *initiate* sustainable mass poverty reduction in low-income areas. How much, if at all, will transgenics help?

Supply of Transgenics, Changing Research Economics and Seed Science

In the GR, supply of seed research to developing countries came mostly from public-sector institutions, under pressure to follow, in part at least, a public-purpose agenda.

Perhaps 90–95 per cent of applied transgenics research, however, is managed by a few large private companies, seeking appropriable profit opportunities. Profits are less, and/or less appropriable, when seeds are self-pollinating (for example, rice, wheat); when they go to numerous dispersed small farmers (for example, millets); and when they embody traits prioritised by such farmers (for example, risk reduction, rather than labour-saving). Why should companies pay to develop such seeds?

One answer might be 'because the public sector decides to make it pay'.[30] It is too pessimistic to say that this cannot be done: that anti-poor, labour-saving bias in agricultural research outputs is an inevitable response to growing labour shortage (and rising wage-rates) in rich countries.[31] Public action influences research rewards. Also, the 'supply side of science', from Crick and Watson through to plant breeders, is not *only* a response to such rewards. True, rewards respond to peer pressures and career incentives, and (especially at the sharpest end of applied science) these are partly created by firms that *do* respond to factor and product prices. But that is not the whole story.

Modern seed research has been informed by insights from basic science, generating 'watershed' innovations – sequences of improved varieties – that raise the conversion efficiency of land, water, sunshine, plant nutrients, and pest management into crop. This basic-science impetus is enhanced in transgenics, because gene insertions, even if designed for crops grown and consumed mainly by the rich, are often suitable also for those of the poor.

Another reason why big-company motivation need not drive out poverty-reducing priorities, is the still-large public seed-research sector.[32] True, it is small compared with private companies, and (China apart) probably cannot *alone* achieve a big shift in transgenics outcomes. However, it can greatly *change incentives* for private transgenics. Large private firms must seek profits, but need not do that solely by charging final customers, with consequent bias towards the crops, traits and regions of interest to large, rich farmers. The public sector, after identifying key poverty-reducing priorities and within an agreed IPR regime, can buy in private R & D for particular tasks, for example, developing high-latency transgenic maize, attractive to small farmers in identified areas. Fee-for-service is feasible, either company-specific or on competitive tender. There are other ways: subsidising 'blue skies' research on company time and equipment, offering substantial prizes, and so forth. Success would draw aid and charitable funds in support. Transgenics companies' need to improve their public image makes this a promising time to develop and explore such options.

IV. Transgenics and The Poor: The Evidence

Of 67.7 million hectares planted to transgenic crops in 2003, 73 per cent were selected for herbicide tolerance, 18 per cent for *Bt*-gene insect resistance, and 9 per cent for both. Herbicide tolerance was induced almost entirely by inserting a gene conferring resistance to damage from glyphosate into soy (41.4 million ha), canola (3.6 m), maize (3.2 m) and cotton (3.1 m). The *Bt* gene in maize (9.1 m ha) and cotton (3.1 m) has induced resistance to corn borer and cotton bollworm. A further 3.2 m ha of maize and 2.6 m ha of cotton have both *Bt* and herbicide-tolerance gene insertions (James, 2004).

Most field evidence is about the impact, not of transgenics as such, but of glyphosate-resistant maize, canola or soy; corn-borer-resistant maize; and bollworm-resistant cotton. These or similar traits have also been induced by conventional plant breeding. Farmers choose a transgenic variety if, and only if, they judge it safer or more profitable. Most arguments, allegedly for or against transgenics, are in fact for or against (a) traits that transgenic varieties embody; (b) the cost, and effects (on the poor, health, environment, and GDP), of obtaining such traits by transgenics vis-à-vis other means: conventional breeding; agrochemicals; agronomic, biological or manual controls; integrated pest or weed management; or crop-mix shifts.

We also need to distinguish *traits* for which transgenic crops now in the field were selected, and the *routes* through which breeders sought those traits. Both may discriminate between poor and non-poor. If a pro-poor *route* to bollworm control in cotton were being designed for poor farmers, a public-purpose agency would attend to their special and extreme vulnerability if resistance breaks down, due to their difficulty in affording or finding extra pesticides quickly, and in bearing risk. Even before gene stacking, *Bt* cotton's resistance to bollworm proved much more stable than expected. But such single-gene, high-level resistance challenges bollworms to develop new biotypes. A more pro-poor cotton breeding strategy would be to seek stable, polygene, moderate resistance or tolerance to bollworm. Biotechnology to understand the functional genomics of both cotton and bollworm, followed by appropriate multiple gene insertions into cotton, seems suited to such an approach, but it is a long haul. Both science and the poor suffer if it is made longer by regulatory restrictions that multiply alongside gene insertions.

Poor and rich alike want better, cheaper, or less poisonous control of insect pests. However, it is usually anti-poor to develop transgenic (or other) varieties for herbicide resistance. This allows chemical, rather than manual, weed control, reducing the demand for labour and hence the wage-rate and perhaps employment. There are exceptions. In some West African uplands, the switch to herbicides, by freeing up family labour, allows poor farmers *who already control land* to farm more of it. Even then, better herbicide resistance is seldom a high priority for pro-poor transgenic research, compared to (a) higher yields per hectare and per litre; (b) greater robustness under moisture stress; (c) focus on areas neglected by agrotechnical progress in the past 50 years; (d) attainability of these advances for small farmers, staple crops and employment-intensive methods.

How well, if at all, will transgenics, through its supplying institutions, address these goals? That is the main factor affecting its long-run poverty impact. However, transgenic outcomes for overarching, polygene traits such as moisture-stress resistance is some way off. Meanwhile, what is the poverty impact of what transgenics mainly does now: inserts *Bt* and glyphosate-resistant genes?

Transgenic Insertion of Bt Insect (Bollworm) Resistance in Cotton, and Analogues

'*Bt* cotton' is code for a range of varieties with a *Bt* gene insertion. These were designed for, and first spread to, large growers. From nil in 1996, *Bt* cotton spread to

4.8 m Chinese farmers (almost all small) on over 2 million hectares in 2001, that is, 43 per cent of China's cotton area. In India, South Africa, Mexico and Argentina, similar varieties have reached millions more small farmers and many large ones (Frisvold et al., 2006). *Bt* cotton has affected the poor through:

- Less pesticide use, with lower costs for adopter-farmers and better health for labourers and farmers: such effects are substantial only where pre-*Bt* pesticide use was *high*.
- Higher yield: important only where pre-*Bt* pesticide use was *low*, or in 'bollworm surge' years.
- Higher net farm income for poor adopter-farmers, due to these two factors combined.
- More employment where few pesticides were used pre-*Bt* (*smallholder Bt* adoption in South Africa and Argentina) and/or bollworm 'surged', so *Bt*-induced rises in harvest labour outweighed falls in spraying labour.
- Otherwise, *less* employment, harming poor labourers (Mexico).
- For similar reasons, less employment in China,[33] but without loss to the poor, because (due to land equality) the fall was in voluntary self-employment, hired farm labour being minimal.

Where pre-*Bt* pesticide use was very high, as in China and Mexico, yield gains from small-farm adoption of *Bt* cotton are small; income and health gains, both mainly due to reduced pesticide use, are large; and employment effects are negative. Further, despite health and income gains to poor farmers and labourers, '*Bt* cotton's success has attenuated its benefits. Rising yields and expanding area has begun to push cotton prices down. As a result, some of the gains that accrued previously to producers are now being enjoyed by consumers'.[34] Where small farmers' pre-*Bt* pesticide spraying was lower (as in Argentina and South Africa), *Bt* adoption raises yields, only modestly reduces the already low pesticide use levels, and on balance increases employment, because the effect of higher yield in raising demand for harvest labour outweighs the effect of modest cuts in demand for spraying labour.

In India there are competing claims, NGO-mediated and company-mediated. However, there is little objective field evidence on transgenic cotton spontaneously managed by farmers (as opposed to field trials). Poor and other farmers are 'voting with their feet' in successive years for *selected Bt* cotton varieties. In October 2002, Qaim and Zilberman (2003) reported field trials showing that 'the amounts of pesticides applied . . . were reduced to one-third of what is used in conventional cotton, while – under severe pest pressure – yield gains were 80 per cent and higher'. Consequently, 'medium-term projections show sizeable welfare gains for the overall economy, with small-scale farmers being the main beneficiaries'. Qaim and Zilberman[35] 'looked more closely at 2001 data from 157 farms in Maharashtra, Madhya Pradesh and Tamil Nadu. *Bt* cotton yielded 80 per cent better than identical cotton without the *Bt* gene, and 87 per cent better than the local hybrids'. Roy et al., in this issue, explore a wide range of outcomes, dependent on variety and farmer, in a low-infestation year; *Bt* varieties, legal and illegal, were favoured by farmers.

Several distinct *Bt* cotton varieties, some with Indian research and/or public-sector involvement, are at various stages of multi-location field trials, clearance for release, and commercial use in many states of India. Effects vary with experience, location, pre-*Bt* pesticide type and level, weather (does *Bt* cotton outperform competing varieties most when pesticides wash off them?), and numbers and biotypes of bollworms.[36] In Gujarat in 2002–03, smallholders and breeders illegally crossed Mahyco/Monsanto *Bt* cotton with local varieties, yielding cheaper seeds that they believe to be better suited to local conditions.[37] Gujarati farmers seek appropriate *Bt* cotton varieties, especially if they can pay non-monopoly prices, but some are willing to pay the Monsanto price as well, depending on their experience and local conditions, as Roy et al. (2007) document. This might seem fine: the market is working, and environmental effects have been tested in a wide range of *Bt* varieties across millions of smallholder hectares from China to Mexico. However, if varieties – *transgenic or other* – wholly escape regulation or validation, might poor, remote farmers fall victim to snake-oil salesmen?

Virulent opposition to *Bt* cotton in India is not simple anti-transgenics or anti-market foolishness. There are genuine uncertainties. Loss of seed quality can lead to significantly lower yields than are available from 'official' varieties. Absence of refugia can cause loss of biodiversity (Western India is the world Centre of Biological Diversity for cotton). If royalties are avoided, private transgenics inputs may be withdrawn. These are not trivial side-effects, for the poor, of desirable democratisation and marketisation of small-farm seed access – what Herring (2007) calls 'agrarian anarchocapitalism'. Keeping professional breeders in the game may require shifts: from 'smallish royalties for ever' to 'one-off fee for service'; and from (bogus) law enforcement to efficient extension and collection, as the means to monitor environmental impacts.

The price regime and trajectory are crucial for small farmers. Globally, *Bt* cotton benefited rich farmers in rich countries first, rich farmers in poor countries next, and poor farmers in poor countries last. When poor farmers lacked *Bt* crops, rising world production (due partly to rich farmers' *Bt* varieties) depressed prices and incomes for poor farmers in the developing world. These, therefore, lost from price falls, both when others adopted *Bt* varieties, but also by benefiting less when they eventually did get *Bt* seeds. This denial of economic rent to latecomers – much the same as poor farmers – is familiar from the GR. What follows?

First, then as now, the cure is to get technical progress to the poor quickly, and to tailor traits to their needs. The alternative is perverse: to restrict technical progress. Then, the poor get not even the crumbs from the rich man's table.

Second, to tailor transgenics or other researched traits to poor people's needs, one has to look at the timed *work environments* of *local* groups of the poor. *Bt* cotton reduces demand for spraying labour and raises demand for harvest labour. Potentially, the former harms, and the latter benefits, the rural poor to the extent that (a) (cotton) land is fairly unequal; and (b) farmwork is a major component of potential extra income for the poor.[38]

Third, a pro-poor transgenics planning process should also look at the timed *risks* facing local groups of the poor. *Bt* cotton's resistance to bollworm, like *Bt* maize's resistance to corn borer, has lasted many years longer than expected, and has been 'refreshed' by gene stacking. However, *Bt*-resistant bollworm biotypes will develop eventually. Small, poor farmers, who are most information-deprived, and whose risk situation makes them least able to mobilise cash, are least likely to find appropriate reserve pesticides swiftly should this happen. The answer is *not* to delay the spread to poor farmers of *Bt* cotton. It is to create public-private partnership actions to alert small farmers to early signs of *Bt* resistance breakdown and to provide the means for rapid remedy.

More important is the long-run lesson. Concentration on highly resistant crop varieties that maximise challenge to the pathogen, and on single-gene resistance that maximises plant loss if the pathogen successfully develops a new biotype, is risky, and thus anti-poor. The alternative strategy of seeking polygene, moderate resistance to (or tolerance of) pathogens has, however, so far been slower, harder, and less matched to the professional incentives of the plant sciences. But might biotechnology (not just transgenic plants) change this? Public-sector and Monsanto-based efforts have provided a near-complete, public-domain rice genome; work at the John Innes Institute has established that this accurately models most other cereal plants; and almost every month more (though still little) is known about the functions of genes, and proteins, in cereal plants. Feasibility and timing are a matter for the scientists; but economists can point to risk-reducing advantages for the poor, whose influence on these decisions is small.

The Case of Transgenic Glyphosate Resistance

Despite real problems and cautions, resistance to a small set of very damaging insects by way of the *Bt* gene helps poor farmers. So, as a rule, does a shift towards pest control through affordable seeds, rather than costly and dangerous pesticides. However, the poor's 'top 50' priorities, if compiled by them prior to transgenics research, would not have included better weed control through resistance to the herbicide glyphosate (Roundup).

There are non-transgenic varieties that resist various herbicides too. But, since glyphosate resistance is inserted into over 80 per cent of transgenics crops in the field, it raises the issue: what are the effects of transgenics research, managed (for non-public purposes and large farmers) so as to select possibly labour-displacing goals? This is a bad use of transgenics resources from the standpoint of poverty reduction relatively, but not necessarily absolutely. Labour-displacing seeds will not be adopted by farmers unless profitable, that is, normally, unless they cut unit costs. That tends to push down prices and help consumers. However, glyphosate-resistant seeds, and linked replacement of labour by herbicides, can harm the poor by cutting demand for labour. That effect was not significant in Argentina or even Paraguay, where mainly big-farm adopters previously used little weeding labour (costly in a middle-income country), preferring chemical or mechanised weed control, with or without glyphosate-resistant varieties (G. Traxler, personal communication, 2004). However, in South Asia (with lower wages and hence much more handweeding), glyphosate-resistant crops – while raising yields and cheapening food – would also significantly displace weeding labourers, usually women and among the poorest of the poor.

In Colombia, an *ex ante* analysis of the impact in 2016 of transgenic herbicide-resistant cassava production reveals substantial gains in producer and consumer surpluses, but a loss of 25 per cent (over two million person-days per year) of employment.[39] Consumers of cassava, even more than those of soybean, tend to be poor. Pachico et al. (2002) comment that, though glyphosate-resistant cassavas:

> . . . might appear to risk jeopardising the welfare of workers in an economy (with) high unemployment, (there would also be a rise in) labour productivity, and thus in principle wages . . . the welfare issue (of employment creation) should perhaps be seen as part of the overall macroeconomic performance of the economy instead of a matter that can be resolved through a single line of production like cassava.

A similar defence can be made for computerisation of banking in India: major gain to consumers is worth more to GDP, and perhaps to the poor, than the cost to workers of shifting employment. There is, indeed, a case against 'loading labour absorption or employment generation on plant breeding'[40] – *if* the losers (as in the banking case) are not the most poor and vulnerable, or if government mounts (or buys in the marketplace) measures to compensate, or retrain and resettle losers. However, Latin American cassava weeders are often landless, resident in remote and marginal uplands, and/or female *indigenos* with a non-Spanish first language (Psacharopoulos and Patrinos, 1993), and as such among the poorest, least educated, and hence least mobile of workers. With such vulnerable losers – unless they are compensated, for example, with reform lands – one cannot so readily absolve labour-displacing innovation. This is normally a *cause of falling* rural wage-rates. In other circumstances – where herbicide-resistant varieties are a *response to rising* rural wage-rates and urbanisation in a booming economy; where weeding is anyway largely mechanised; where weeding employment provides little of the income of the rural poor; or where rates of cropped area expansion exceed rates of reduction in labour-demand per hectare – there may be net poverty reduction effects from herbicide-resistant varieties.

In much of Asia and in some areas elsewhere, farmers often hire as weeders near-landless or landless women, often from ethnic groups or castes with mobility hampered by language, poverty or illiteracy. Reduced demand for their labour, and hence cuts in their wage-rates, harm the most vulnerable of the poor. This makes a case, not for banning such varieties (infeasible anyway), but for introducing public-purpose incentives to future transgenics breeding choices.

What about arguments that, in some developing rural areas, labour rather than land is scarce, so that innovations that lower the per-hectare demand for labour are desirable? Such arguments are suspect. First, labour scarcity is often, maybe usually, a claim made by employers seeking to justify even lower wage-rates. Second, many parts of Africa that had spare croppable land twenty years ago do not have it now. Third, most of the few remaining places that have spare croppable land now – as research priorities for transgenics are set – will no longer have it when that research delivers. Fourth, much remaining spare land is croppable only at high risk to biodiversity (Amazonia), or of overfarming and exhausting land-water systems better left in extensive grazing (parts of East and Southern Africa).

Finally, special cases for relieving a labour limitation are almost always seasonal, or to permit timely, early planting despite a workforce depleted by HIV/AIDS. Seasonal labour shortages, where labour still earns little, require farming methods (including new seeds) to shift the labour peak, not to cut overall labour demand and thus push down employment and wage-rates. As for HIV/AIDS, it can severly cut labour supply, but this is short-term and often local. It does not mean that plant breeders should prioritise cutting crop demand for labour and hence the income of the poor, including working relatives of HIV/AIDS sufferers. Also – with 5–15 year lags from new breeding strategy to widespread field adoption – labour-saving strategies cut against big medium-term rises in workforce.

If rich farmers cut costs by selecting transgenic varieties for herbicide resistance (or other labour-displacing traits), must poor farmers imitate or die? That is too gloomy, for three reasons.

- It takes too homogenising a view of agricultures. Public policy for research and innovation, as well as for employment, can run with the tide of factor scarcities, steering research into more socially desirable channels.
- It is too limiting a view of science. Can national research do more than adapt, screen, or at best locally cross varieties with gene insertions from elsewhere? Yes, but only in the few developing countries with strong enough research capacity. Such countries are, almost by definition, big; but most of the world's dollar-poor live there.
- It downplays the role of the public sector: in sponsoring applied research (transgenics-based and other) corresponding to its own poverty priorities; in changing incentives to affect private-sector research aims; and in regulating varieties and imports both before and after field trials.

The latter is a controversial area. In general, governments should *reduce* the regulatory delays and costs that keep the benefits of transgenic crops away from poor farmers. However, plants such as *Lathyrus sativus* (the lentil *kesari dal*, known to cause lathyrism) are rightly restricted in many countries. Could it be right to discourage the planting of varieties, whether conventional or transgenic, that cut employment and increase poverty?

Key Crops, Pipelines and Hypelines: Reflections on Golden Rice

Vitamin A deficiency, a major cause of death and blindness among under-fives, is prevalent among poor people with rice as their main staple. They can seldom afford well-diversified conventional vitamin A sources. Vitamin A precursors cannot be inserted into rice *grains* except by transgenics. The 'Golden Rice' programme is a credible use of transgenics to help people too poor to afford conventional vitamin A sources, and is more cost-effective than supplementation or fortification (H. Bouis, this issue). Before we explore what 'Golden Rice' tells us about the poverty impact of transgenics regulation, biosafety and priorities, there are two prior questions. First, what role have staples, vis-à-vis cash crops, in poverty-reducing transgenics research? Second, how can non-specialists – including most research planners and economists – make sense of the welter of PR hype supporting, and NGO hype opposing, ongoing transgenics research?

Staples and transgenics. Though the poor can gain from applicable research into main smallholder cash crops, the poor lose from the focus, so far, of transgenics on 'cottonseed and chicken-feed' (soy, yellow maize) instead of main staples. Despite steady real price falls and some income rises, the dollar-poor still typically spend 50–60 per cent of income on staples alone, and derive 70 per cent of calories (and most proteins and micronutrients) from them. So transgenics making staples cheaper offer the poor, as consumers, potentially big gains in income and nutrition.[41] However, most of the world's poor – mainly farmers in Africa and China, and mainly farm-workers in South Asia – obtain their main income from small farms,[42] largely growing staples. Increases in such income are increasingly constrained by shortage of land and water. It is therefore important that transgenics-led innovations walk the second tightrope (pp. 31–32), so gains for the poorest as consumers are not offset by losses as producers or employees.

It is seldom in the interests of transgenic-seed companies to focus on staples grown by small farms in low-income countries. Regulatory costs and barriers are high.[43] Unfavourable public relations have been created, by unwise company actions and by some NGOs. It is in any event hard for companies to get a normal return on such R & D investments. It is hard to collect seed or technology charges on food crops, often self-consumed or sold outside formal markets, from millions of tiny farmers. It is hard to stop them retaining transgenic seed to replant or sell to neighbours, especially for self-pollinated crops such as rice and wheat; from crossing transgenic seeds with their own varieties; or from otherwise cutting 'monopoly' rent (on large and risky research costs) by breaching what firms regard as their intellectual property rights (IPRs). Monsanto, far from foisting transgenics on the poor, has pulled out of transgenic rice development (after first putting its knowledge of the rice genome in the public domain).

Nevertheless, there is scope for transgenics research to improve staples performance on small farms and for poor people. First, once a company has profited from a successful gene insertion into a non-staple crop, it can test the same gene's impact after insertion into staples. Even if not profitable, the PR may do more for the bottom line than IPRs, which are often unenforceable; it is in the interest of private companies to be seen to act in the interests of the world's poor. Second, private-sector scientists, directors and shareholders often prefer moral to immoral action. Third, as for public-sector crop research institutions, their income depends partly on impact on the millennium development goal of halving dollar poverty in 1990–2015. Personal commitment apart, public agencies may find it cost-effective to stimulate private researchers to shift towards that goal, through public-private partnerships, fee-for-service, prizes, or other means. Finally, there is a growing not-for-profit sector supported by philanthropists through foundations (compare the 2003 announcement of $25 million support by the Gates Foundation for the CGIAR 'challenge grant' work on staples bio-fortification: Bouis, this issue).

Hype for and against staples transgenics. Contributions from transgenics to poor people's staples have been announced, sometimes many times. Nuffield (1999, 2004) reported the claims: that:

> ... inserting genes from two wild rice relatives into the best performing Chinese rice hybrids has raised yields by 20–40 per cent. Research ... has produced a transgenic rice variety resistant to the tungro virus ... potato varieties bred in

> Peru with stable multi-gene resistance to late blight, a wild wheat cross yielding 18 tonnes/ha. (Nuffield, 1999: 4.29)

> ...improved resistance to environmental stresses such as cold, moisture-stress and high salt levels in the soil...achieved in transgenic rice; transgenic bananas [showing] the possibility of achieving protection against serious fungal diseases and reductions in applied pesticides [with] a more diverse range of varieties, which would allow for additional protection against the impact of pest infestation. (Nuffield, 2004: 43)

What happened to such work-in-progress?[44] In 2003, below 0.05 per cent of transgenics area was planted to any main food staple,[45] including those recorded above (James, 2004).

Committed researchers innocently oversell the potential, perhaps especially when their motives are more moral than commercial. This is well known in natural resource management research (micro-watersheds) and conventional plant breeding (the gap between claims, spread and performance of high-yielding cassava in West Africa). The transgenics examples have proof of concept, and usually plants and seeds with the characteristics claimed, but little in trials and less in farmers' fields. One reason for pro-transgenics hype is reaction against anti-transgenics hype. Inflated, pseudo-scientific health and environmental bugbears have led to delay, over-regulation and even destruction of transgenics research, trials and commercial releases, especially for food and above all for staples. Researchers overclaim partly because they feel beleaguered by anti-science, innuendo and suspicion. But that does not justify the extent of 'transgenic overclaim': the pervasive, counter-productive, and long lag (or permanent gap?) between claim and gain (or grain). It is normal, even with no hype, for 5–10 years to elapse between the start of research and the release of a commercial variety. Yet faster pre-selection is a strongly (and credibly) claimed advantage of transgenics.

Provitamin-A-enhanced rice. The main target for transgenics or other staples breeding is to raise and stabilise sustainable yield, water productivity and employment income. Micronutrient enhancement, while important to the health of the poor, is secondary, and is often best achieved by non-transgenics breeding: consumers of IRRI's pioneering ferritin-enriched rice showed greatly improved iron status (Haas et al., 2005). Sometimes, however, transgenics is the best way to enhance a plant as a source of a bioabsorbable micronutrient.

With vitamin A in rice, it is the only way (Bouis, 2007). And vitamin A deficiency (VAD) overlaps strongly with poverty in rice regions. In 1995, three million children had xerophtalmia, the main cause of child blindness; a further 11 million had clinical VAD; and a further 250 million had sub-clinical VAD, raising the risk of infections such as measles (ACC/SCN with IFPRI, 2000). At least a third of VAD is found in Asia, mainly among poor consumers for whom rice is the main staple. Rice is unique as a staple (a) eaten by most of the dollar-poor (most are Asian); (b) absent transgenics not a source of vitamin A for humans; (c) especially in flooded flatlands, often a monoculture for agronomic reasons, so non-staple sources of vitamin A, such as amaranth, are often unavailable.[46] But is transgenic β-carotene-enhanced rice feasible; attractive to farmers, sufficient as a source of bio-absorbable vitamin A, likely to reach those with VAD, or a cost-effective way to cut it?

On feasibility, Beyer et al. (2002) experimentally transferred four relevant genes. After negotiating the necessary patent clearances and material transfer agreements from the companies involved, they inserted these genes in 2002 into IR-64 – the most widespread conventional semi-dwarf rice, which at present has adequate resistance to all major pests of rice. Photographs of small piles of 'goldenised' IR-64 have been published in peer-reviewed journals (Paine et al., 2005).

Farmer acceptance will depend on profitability and risk. Testing for these means crossing, selection and field-testing. National regulatory clearance is needed for the four gene insertions separately and jointly. Field tests also need to monitor environmental risk, while laboratory and other tests check allergenicity. Deregulation for countries participating in the Golden Rice Network (India, China, Indonesia, Vietnam, Bangladesh, the Philippines, and South Africa) has proved onerous. Influenced by the European debates, regulatory agencies have been hesitant to grant licences for field trials. Companies have removed constraints on smallholder planting, though they can, in theory, charge rich farmers (tightly defined) a royalty. Rice is self-pollinating, so 'Golden Rice' seed can be replanted or sold by farmers without effective constraint. However, the legal situation is cloudy in countries having most rice staples consumers with VAD: China, India, Indonesia, Bangladesh. In early 2004 key researchers *hoped* to complete field tests in the Philippines by 2007; by early 2005 they were estimating a further delay of five to eight years before significant quantities of Golden Rice reach consumers.

On sufficiency of vitamin A from transgenic rice, there is both rapid change due to work in progress, and much controversy due to extreme estimates by both supporters and opponents. Three issues determine how useful 'Golden Rice' will be to those with VAD:

(a) Per kg of rice, how many micrograms of β-carotene?
(b) Per microgram of ß-carotene in rice, how much humanly bioabsorbable vitamin A?
(c) Per unit of bioabsorbable vitamin A, how much 'gain', at different degrees of VAD?

On (a), 160 micrograms of β-carotene per 100 g of cooked rice were found in the earliest tests, but successive transgenic varieties claim dramatic improvements. On (b), on a gloomy view, β-carotene from Golden Rice converts to vitamin A at 12:1, the same as from leafy greens; Bouis (this issue) suggests a better ratio and the optimists assume 4:1, and the optimism seems to be confirmed by recent and ongoing Tufts-USDA studies (Bouis, personal communication).[47] On (c), the usefulness of extra vitamin A probably *increases* as initial VAD rises; the definition of VAD is such that VAD-related diseases in the average child are prevented by *half* the recommended daily allowance.

By combining the gloomiest assumptions on (a), (b) and (c), Greenpeace claimed that a child must eat an impossible 3 kg a day of Golden Rice to make a useful impact on VAD risk.[48] On more optimistic assumptions, the fathers of 'Golden Rice' estimate 200 g, giving enough vitamin A *even with no other source* to prevent most

VAD-related diseases.[49] Since then, there have been very substantial increases in the provitamin-A content of transgenic rice, though new gene insertions which still require regulatory approval.

Whether or not transgenic rice is the most cost-effective approach to VAD depends on acceptance by farmers and consumers. Howarth Bouis (2007) compares alternative approaches. *Commercial fortification* worked well in the case of iodised salt, and cost-effectively cut iodine deficiency for large populations, but badly for VAD. *Vitamin A megadoses* were strongly advocated for schoolchildren once, but (save for acute or hospitalised cases) no longer, suggesting that the approach was not very cost-effective, and/or that those most needing help are pre-schoolers or school-age non-attenders, both heavily overrepresented among the poor. *Dietary diversification* into non-staple sources of β-carotene is ruled out in the short term by poverty. *Nutrition education* is promising only in the small minority of cases of VAD due to parental ignorance. *Non-transgenic breeding* is infeasible for vitamin A enhancement of rice. Other paths may have their place in a strategy against VAD, but it is implausible that the mass of cases among the rice-eating poor will be tackled rapidly or cost-effectively by such methods alone.

It has been estimated that each year of delay in 'Golden Rice' brings the Philippines 9000 more blind children and at least 60 extra deaths (Zimmermann and Qaim, 2002). The Asia-wide numbers would be at least 30 times higher (scaling up from the Philippines to Asian rice-staple populations and allowing modestly for the latter's generally worse poverty and undernutrition). The large majority of VAD sufferers, and hence potential beneficiaries, are poor.

V. Lessons for Transgenics from the GR: Some Tentative Conclusions

It has become clear than most poverty and hunger are linked to inadequate staples *entitlements*. Yet the GR successfully brewed poverty reduction out of seed improvements designed to raise staples *availability*. Also, GR did less well at cutting poverty by raising the poor's entitlements when (since 1990) and where (most of Western China, East–Central India and Africa) it did less to raise staples availability. Sections II–IV suggest two alternative assumptions underlying this paradox, implying distinct lessons for transgenics.

- Assumption 1: *The GR worked, and helped the poor, only when and where there was adequate support for plant-productivity research in the international and developing-country*[50] *public sectors, because these are more responsive than profit-motivated companies to the poor's needs and criticisms*. Transgenics companies seldom find it profitable, given the costs of research and regulatory management, to prioritise the poor's central trait requirements: higher yields and greater robustness for staples in water-insecure environments. Risk-averse or royalties-motivated scientists and companies will seldom prioritise these traits. Though probably amenable to transgenics, such traits are *recalcitrant*: complex, polygene, and with high risk of research failures and difficulty in appropriating royalties from millions of tiny farmers. Mainly private transgenics research may yield significant incidental gains to the poor (Section IV), but on Assumption 1 the

central, recalcitrant traits needed by the poor will not attract much private-sector research.
- Assumption 2: *The GR addressed the entitlements problems of the poor –'walked the tightropes' – due less to its public-sector, publicly accountable origin than to the yield- and robustness-enhancing bias of modern seed research and innovation.* If so, the poor's central trait requirements will be helped, in the long run, by almost any new impetus from basic science to seed research. This is especially likely with the impetus that produced transgenics, because it is not specific to the host crop. On Assumption 2, whether the *motive* of transgenic seed research is profit or the public good, its *long-term outcome* is likely to benefit the poor, in adopting areas, substantially and fundamentally (as did the GR), not modestly or by chance side effects (as with transgenics so far). The poor may still lose from specific transgenic innovations (for example, better herbicide-tolerance that displaces weeding labourers), or from innovations heavily concentrated on competitors against poor farmers. That need not invalidate the pro-poor potential of any powerful new tool of seed science. The tool, as a source of new products, cannot be monopolised for long, or confined to rich beneficiaries, even if particular manifestations of its product may be.

Whether Assumption 1 or 2 applies, our earlier analysis raises six challenges:

- The poor and immobile in *non*-adopting areas, especially to the extent that they trade, will lose heavily if their competitors acquire transgenic seeds. It will be harder to escape uncompetitiveness by shifting the crop-mix than with GR, partly because transgenics is less host-crop-specific. Transgenics-free zones catering to non-transgenics markets are unpromising.
- Paradoxically, company monopolisation of seeds (given the inappropriateness to poor farmers of many privately researched traits) can hand seed control to poor farmers, as they are induced to obtain transgenic seed legally or otherwise and creolise it to suit their trait preferences (see Herring; Roy et al., 2007).
- Though such farmer power over transgenics is in many ways welcome, the external and environmental risks argue – even if Assumption 2 is correct – for more public-sector, publicly accountable transgenics research (and more incentives to reorient private-sector research) that seeks *sustainable* crop traits sought by the *local* rural poor. For instance, while private transgenics may brilliantly create single-gene resistance to a pest, only public action is likely to address the intersection of the poor's (private-good) and the environmental (public-good) needs for sustainable, horizontal (polygene), moderate resistance or tolerance.
- Widespread small-farm adoption of transgenic crops in some developing countries – and the likely spread of small-farm adoption to more crops, traits and countries – underlines *the need to see bio-safety management as participatory extension with teeth, not as legalistic regulation.* The latter may make sense for rich countries with many technicians and a few hundred giant farms, but it is elsewhere doomed to failure.
- Regulatory restriction on transgenics seeks to cut (sometimes real) environmental and (largely bogus) health hazards. Regulations would be fewer, simpler and quicker if legislators considered, as they should, the (almost unassessed) hazards

of non-transgenic varieties, including those bred conventionally – and the hazards of delaying transgenic varieties: more VAD, greater pest risk, and loss of competitiveness, especially for the poor.

- Finally, developed countries' transgenics strategies matter to the poor of the developing world. If EU regulations stop transgenic imports, developing countries are deterred from adoption.

A cross-cutting influence on how transgenics follows up GR as an engine of poverty reduction is how agricultural-resource, demographic and nutritional situations, in the years of probable transgenics spread in developing countries, *differ* from the situations during the GR.

How a big technical change such as the GR or transgenics affects poverty depends on both social formations and initial situations. The GR changed those radically. In 1960, perhaps three-quarters of the world's dollar-poor lived (overwhelmingly from staples production) in Bangladesh, China, India, Indonesia, Mexico, Pakistan, the Philippines and Bangladesh. Today, these countries have better than halved dollar poverty (in GR regions, much better). They still contain over half the world's dollar-poor, mainly rural,[51] but often depending for income mainly on cash crops, rural non-farm sector activity, and urban work. Once the Green Revolution has slashed poverty and labour is shifting from the land, much poverty reduction can come mainly from such non-farm sources. Most of the world's dollar-poor, however, still mainly depend on agriculture – in Africa and some of Asia, still largely staples farming. They are unlikely to escape poverty unless nearby farm employment grows and becomes more productive, creating the mass demand to permit later shifts to cash crops, rural non-farm activity, and urban work. The *initial* escape route from dollar poverty is likely to be through cereals-based, labour-intensive farm production and employment. In steering through that escape route, transgenics appears well placed to improve productivity of crops adapted to agro-ecologies recalcitrant to seed-fertiliser-irrigation-based development. Transgenics is also well adapted to address the intensifying water crisis (Nuffield, 2004: 3.42), though it will need help from new water science. Though it is imperative to avoid hype, seed science is pointing in the right direction. But its increasingly private owners do not face sufficient incentives to seek the right goals. Changing that depends on human agency.

Notes

1. (i) 'Green Revolution' (GR) and 'genetic modification' (GM) are 'code': GR, for bred changes in plant architecture (including rice and wheat dwarfing) and in stress resistance, applied in developing countries in 1963–85; GM, for transgenics. The codings are inaccurate and unfortunate – see Herring's Introduction to this issue – but save space and semantics. (ii) 'Poor' in this paper means dollar-poor, admittedly a very restricted meaning (Lipton and Ravallion, 1995). (iii) Some primary sources are in Nuffield Council on Bioethics 2004 (Working Group: D. Burke, M. Gale, M. Lipton, S. Thomas and A. Weale). Nothing in this paper is necessarily the view of, or should be attributed to, the Working Party or Council.
2. Except for nutrition, there is little guidance to impact of agrotechnical change specific to the well-being of the *non*-working poor (mainly small children, women in late pregnancy, the aged, and the ill). In most developing countries their incomes normally depend almost wholly on, and hence rise and fall with, those of the working poor.

3. The rural poor comprised over 70 per cent of the world's dollar-a-day poor around 2000, and are projected (despite urbanisation) to comprise over half until 2035 (Ravallion, 2000).
4. In the 1970s and 1980s, plants with (more or less unknown) chemical- or radiation-induced mutations were widely planted, without regulation or containment, in an effort to improve GR outcomes. Such chance experiments carried massively greater dangers of unwanted crossing than do today's contained trials of plants with known gene insertions, yet escaped largely without complaint from environmentalists or NGOs.
5. Despite the recent award of a World Food Prize for 'quality protein maize', no persuasive new evidence threatens this 30-year-old 'Gopalan consensus' (Lipton with Longhurst, 1989: 244–6). However, the consensus is rejected by one of the world's most distinguished nutritionists (Dr Nevin Scrimshaw).
6. For discussion and references see Strauss and Thomas 1995. In the 1970s surveys reported calorie-income elasticity (CIE) as low as 0.1 *at the mean* in some poor groups. However, later work suggests CIE closer to 0.4 in the poorest deciles. CIE apart, nutritional status also rises as extra income leads to health-seeking behaviour. Also, GR seeds make staples cheaper and – if they are on one's own farm, paid as wages, or sold nearby – easier to obtain. The debate about CIE continues; the problem is partly how to increase it! Some people within a community, and some communities and cultures (for example, with less feeding bias against girls), show 'positive deviance' and thus have far less protein-energy (and perhaps micronutrient) malnutrition even when poor; GR or transgenics impact may vary among households or communities. More knowledge here could improve transgenics impact on nutrition for those at risk. GR success with staples induced farmers to divert land from other protein sources such as pulses in South Asia. However, protein loss from pulses was outweighed by protein gain from more, cheaper rice and wheat. So, if transgenics digresses in search of higher protein content, the nutrition of the poor may well suffer.
7. Sundaram and Tendulkar (2002: 43). Many households get income from more than one source.
8. Lipton with Longhurst (1989: 178–88), and sources cited there. It is wrong to read such falls (for example, from 40 per cent to 15 per cent) as 'declining elasticity of employment to yield growth'; most of the falls (due to tractors, reaper-binders and weedicides) would have happened whatever the yield growth, and were therefore softened by it. The falls also affect the poor in non-GR areas, limiting their migrant labour income. On the large scale of such income, see David and Otsuka (1994). Migrant labour also cuts labour supply, and so bids up real wages, in the non-GR source areas.
9. Even then, research planners should ask: would the poor gain *more* if the same research resources were applied to, say, water-economising rather than herbicide-resistant varieties?
10. That is, allowing for effects, if any, of the new variety on crop-mix; on urban-rural, intersectoral and interregional flows of inputs, outputs and spending; and on prices.
11. Because of concentration by area, an increasingly large part of national staples output in, say, India fell when there was a bad year for wheat in the Punjab. Higher inter-farm covariance outweighed lower within-farm variance; the coefficient of variation of national staples output rose. See Hazell (1984: 302–11).
12. As happened twice in 1972, after tungro virus attacked SE Asia's highly popular IR22 rice, while *H. Maydis*, Southern corn blight, attacked the currently most widely planted maize hybrid in the US.
13. It is fashionable to *claim* that 'African' soil-water regimes are inherently more variable, unstable or fragile than 'Asian', and to *infer* that 'African' plant breeding should not seek a widely usable variety, but many varieties for many agro-ecological niches. The claim is baseless. Even if it were not, the inference would remain false.
14. As with the wheat-dwarfing gene, this rice newcomer expresses gibberellins, raising yield additionally to the effect of dwarfing.
15. However, to *maximise* biodiversity, the preservation of older non-transgenic varieties is increasingly important, depending mainly on comprehensive, well-maintained formal collections. It is doubtful whether long-run risk-minimisation is practicable mainly via in situ conservation and/or non-transgenics refugia, especially in land-scarce countries with hundreds of thousands of tiny and inevitably loosely regulated farms.
16. The alternative of environment-saving yield growth through a more varied crop-mix, while viable locally, is infeasible globally due to the shift of world demand towards animal products, which raises demand for feed cereals.
17. 'If world crop yields had not been tripled [in 1960–19]92, we would have ploughed 10–12 million square miles of additional uncultivated land for low-yield crops. To avoid this happening [from 1992], we must . . . triple the yields from the world's existing farmland again' (Avery 1997).

18. FAOSTAT (updated February 2004). For Sub-Saharan Africa 1.5 per cent excludes, and 3.8 per cent includes, Madagascar, South Africa and Sudan.
19. See Drought-Resistant Soy in Pipeline (2004).
20. See Fitzgerald and Perkins (2005): 'Major seed companies are racing to be first to market with the drought trait. Pioneer Hi-Bred International Inc. and Monsanto Co., among others, are investing heavily in the effort.... More arid grain-producing regions in other parts of the world may have more trouble with drought than the Midwest, but seed companies are focused on delivering drought tolerance first to this market because it is the world's biggest seed corn market'.
21. 'Excluding South Africa, [SSA] accounts for less than 1 per cent of world fertilizer consumption' in 2000–01 (International Fertiliser Industry Association 2004). In 2000, SSA had about 10 per cent of the world's arable land (FAOSTAT, April 2005.)
22. This is proved by the co-existence of non-declining rates of return to staple seed research *for* the developing world from the 1960s to the 1990s with sharply declining staples yield growth *in* the developing world (see, respectively, Alston et al., 2000; Lipton 2000). Seed research must have been achieving its non-falling returns by shifting from yield-enhancement goals towards prevention of (pest-induced) *falls* in yield. This is especially clear as returns to research were maintained while staples prices fell and input costs rose, rendering a given return to research harder to achieve.
23. C. Delgado (1999). If 'filtered' through livestock feed, 5–7 times as many staples are needed to supply enough human energy to humans.
24. Notably with repeated enlargements of EU to include more agriculturally orientated countries (while retaining heavy protection and/or producer and export subsidies for its main products), and with the abandonment by the US (in the 2002 Farm Bill) of the remnants of agricultural free trade.
25. (Make your minds up 2004). General-equilibrium work shows big costs (income and poverty reduction foregone) to developing countries seeking a transgenics-free export market niche (Anderson et al., 2002, Abdalla et al., 2003).
26. 'Transgenics-free zones' that defy the preferences of farmers will prove unpoliceable (Herring, this issue). Soy seeds 'smuggled' into South Brazil from Argentina confirm the infeasibility of regulating, respectively, inter- or intra-national seed movements.
27. This requires area-specific incorporation into breeding goals. In much of Asia, but not in Africa (Svedberg, 1990), the worst-nourished are small girls, prioritising absorbable calories in staples-based weaning gruels.
28. Through more: infections aged 40–60; diabetes; heart disease; and weight gain for urbanisers (Lipton, 2001).
29. On HIV/AIDS and transgenics incentives, see case discussion in this paper of glyphosate resistance.
30. Implications include joint strategising for biotechnology, led by the international public sector but involving all interested, including small farmers, labourers, and poor consumers; public will and capacity to 'buy in' significant private R & D skills in transgenics; and a big rise in public R & D for transgenics with poverty-reducing priorities.
31. Agricultural research tends to produce results (for example, seeds) saving mostly the factor (labour, land or capital) scarcest for the 'customer' farmers (Hayami and Ruttan, 1985). But this tendency does not explain much of the variance in factor-saving bias, which also responds to (a) public research and policy; (b) inherent features of scientific discovery.
32. Some developing-country public sectors (China, India, Brazil, Mexico) have large capacity in biotechnology. The CGIAR has an annual budget of over $300 million: long static in real terms (though perhaps being revived by the challenge grants), diffused over many institutions and purposes, and with below 10 per cent aimed at biotechnology.
33. In S Africa '*Bt*... increases yields by 40 per cent and is pesticide-saving, halving spraying. It is not labour-saving as the extra harvest labour compensates for less spraying labour. The results for small farmers in Argentina are similar, whereas in China there was zero yield gain and a five-fold reduction in pesticide. This is because the Chinese farmers over-used pesticides prior to Bt, whereas these South African smallholders have difficulty obtaining chemical inputs... yield gains should be greater for most smallholders in Sub-Saharan Africa and *Bt* cotton should not reduce employment' (Shankar and Thirtle, 2005; compare Shankar and Thirtle, 2003; Thirtle et al., 2003).
34. Huang et al. (2003). Comparing surveys for 1999, 2000 and 2001, they show that 'adoption of *Bt* cotton continues to increase [yield] in 2000 and 2001... [in] all provinces in our sample... *Bt* cotton

farmers also increased their incomes by reducing use of pesticides *and labour*... [and] have less health problems [due to] reduced pesticide use'. Typically, yield gains were 10%, but vary greatly; see below and Roy et al. (this issue).

35. The paper (in *Science*) is cited in Qaim and Zilberman (2003).
36. Depending on place and time, control of cotton bollworm might leave more cotton to feed other pests, not affected by *Bt*. This would show up in profitablility or income analyses such as that of Qaim and Zilberman (2003).
37. As with (legal) creolisation of CIMMYT maize HYVs by smallholders in Chiapas, Mexico (Bellon and Risopoulos, 1999).
38. Similar differentiation explains why Indian NGOs commenting on early drafts of Nuffield (2004) were hostile, but their African counterparts much less so, to herbicide-resistant crops.
39. Extra land planted to cassava does little to offset falling employment per hectare (Pachico et al., 2002: 356–67).
40. I am grateful to Ron Herring and Ravi Kanbur for the computerised-banking analogy and for this observation.
41. Sen (1981) shows that most famine-affected people, and by extension many chronically undernourished, suffer from lack of entitlements (claims) to food, not of food availability. Some – not Sen – wrongly infer that more food production, for example via transgenics, cannot make the poor less hungry. India's huge public grain stock, alongside mass hunger, is taken to show that (extra) national food production cannot improve food security. This is fallacious. The most cost-effective *feasible* way to raise the poor's food entitlement is to raise their earnings, relative to food prices. The most cost-effective way to do that, in rural Africa and Asia where two thirds of the world's of the dollar-poor live, is usually to raise *nearby, small-farm, labour-intensive* staples production. This is consistent with the fact that more cereals from non-poor Punjabi (or EU) farmers, grown capital-intensively and sold to public stock, do (at best) nothing to reduce poverty or, therefore, hunger.
42. The share of land in farms below 1ha has been rising in all these areas, in 1970–90 and in 1990–2000 (FAOSTAT, 2005). Small farms show higher value-added per hectare (but less per unit of labour) than larger farms (Lipton, 2005).
43. Dr Ingo Potrykus (personal communication, 2003) has emphasised that regulatory delays impose a career disincentive, especially on young scientists, against public-purpose, non-company work on transgenic crops aimed to benefit the poor.
44. Work on transgenic virus-resistant sweet potato – 'in Kenya... estimated to raise yields 15 per cent' (Nuffield, 1999), '[to] prevent dramatic... reductions in yield of [a] major food crop of many poor people in Africa' (Nuffield 2004) – failed, stopping in early 2004. de Grassi contrasts this programme with cheaper, less publicised, more successful conventional breeding in Uganda. http://www.ahbfi.org/sweetstatement.htm 2004 objects to this as hindsight, citing the transgenics work's *ex ante* plausibility, and yield in experience and training.
45. Transgenic soy and yellow maize are almost entirely used for animal feed.
46. This aggravates the poor's difficulty in avoiding VAD through varied diets. The poor need cheap calories to survive; 'let them eat carrots' is not a useful message, especially if non-staple Vitamin A sources do not grow locally.
47. Even these studies do not assess bio-absorption by under-fives with VAD, for example, through breast-milk and rice gruels.
48. Assumptions: very low bio-absorbability; all vitamin A from Golden Rice; uselessness to those with VAD unless it contributes 100 per cent of RDA. (Greenpeace, 2000 [published before the improved new generations of enriched Golden Rice]). Informally, eating requirements are magnified further. I heard 9 kg confidently asserted, without evidence, by a voluble opponent of transgenics at the IDS Sussex conference, 'Biotechnology and the poor', on 1 October 2003.
49. (Beyer and Potrykus, 2003). Requirements would be much lower given the claimed content of new releases to June 2005, but these involve several new transgenic events, each requiring long clearance procedures.
50. Applied in-country research is usually needed, for good returns from seeds researched abroad (Evenson and Kislev, 1976).
51. Seventy per cent of the world's dollar-poor were rural in 2000; more than half will be rural in 2035 (Ravallion, 2000).

References

Abdalla, A., Berry, P., Connell, P., Tran, Q. and Buetre, B. (2003) Agricultural biotechnology: potential for use in developing countries, ABARE *e*Report 03.17, Canberra.

ACC/SCN with IFPRI (2000) *Fourth Report on the World Nutrition Situation* (Geneva: ACC/SCN).

Alston, J., Chan-Kang, C., Marra, M., Pardey, P. and Wyatt, T. (2000) A meta-analysis of rates of return to agricultural R & D: *ex pede Herculem?*, Research Report No. 113, International Food Policy Research Institute, Washington, DC.

Anderson, K., Nielsen, C. and Robinson, S. (2002) Estimating the economic effects of transgenics: the importance of policy choices and preferences, in R. Evenson, V. Santaniello and D. Zilberman (eds), *Economic and Social Issues in Agricultural Biotechnology*, pp. 359–91 (Wallingford: CABI International).

Avery, D. (1997) Saving the planet with pesticides, biotechnology and European farm reform, Bawden Lecture, British Crop Protection Council, Brighton.

Behrman, J. and Deolalikar, A. (1988) Health and nutrition, in H. Chenery and T. N. Srinivasan (eds), *Handbook of Development Economics. Vol. I*, pp. 631–711 (North Holland: Amsterdam).

Bellon, M. and Risopoulos, J. (1999) Expanding the benefits: farmers' transformation of a CIMMYT technology to suit the poor, mimeo, San Jose workshop on agricultural research and poverty, CIAT, Cali.

Beyer, P., Al-Babili, S., Ye, X., Lucca, P., Schaub, P., Welsch, R. and Potrykus, I. (2002) Golden Rice: introducing the β-carotene biosynthesis pathway into rice endosperm by genetic engineering to defeat vitamin A deficiency, *The Journal of Nutrition*, 132, pp. 506S–10S.

Beyer, P. and Potrykus, I. (2003) How much vitamin A rice must one eat?, accessed at: http://www.agbioworld.org/biotech-info/topics/goldenrice/how_much.html

Bouis, H. E. (2007) The potential of genetically modified food crops to improve human nutrition in developing countries, *Journal of Development Studies*, 43(1), pp. 79–96.

David, C. and Otsuka, K. (eds) (1994) *Modern Rice Technology and Income Distribution in Asia* (Boulder: Lynne Rienner).

Delgado, C. L. and International Food Policy Research Institute (1999) *Livestock to 2020: The Next Food Revolution* (Washington, DC: International Food Policy Research Institute).

Evenson, R. E. and Kislev, Y. (1975) *Agricultural Research and Productivity* (New Haven: Yale University Press).

Fan, S., Hazell, P. and Haque, T. (2000) *Targeting Public Investments by Agro-ecological Zone to Achieve Growth and Poverty Alleviation Goals in Rural India* (Washington, DC: International Food Policy Research Institute).

Fan, S., Linxiu, Z. and Haque, T. (2000a) *Growth and Poverty in Rural China: The Role of Public Investments* (Washington, DC: International Food Policy Research Institute).

FAO (2000) Food and nutrition security: why food production matters, in *The State of Food and Agriculture 2000*, (Rome), pp. 199–242.

Fitzgerald, A. and Perkins, J. (2005) Weather worries: hot, dry or wet, DesMoines Register.com, March 27, accessed at: http://www.dtn.com/news.cfm?content=05news/n_032705&sidenav=sn_innews

Frisvold, G., Reeves, J. and Tronstad, R. (2006) Bt cotton adoption in the United States and China: international trade and welfare effects, *AgBioForum*, 9(2), pp. 69–78.

de Grassi, A. (2004) accessed at: http://www.ahbfi.org/sweetstatement.htm

Haas, J., Beard, J., Murray-Kolb, L., del Mundo, A., Felix, A. and Gregorio, G. (2005) Iron-biofortified rice improves the iron stores of non-anemic Filipino women, *Journal of Nutrition*, 135, p. 2823–30.

Greenpeace (2001), Vitamin A: natural sources vs 'golden rice', accessed at: http://archive.greenpeace.org/~geneng/reports/food/VitaAvs.PDF

Hayami, Y. and Ruttan, V. (1985) *Agricultural Development: An International Perspective* (Baltimore: Johns Hopkins).

Hazell, P. (1984) Sources of increased instability in Indian and US foodgrain production, *American Journal of Agricultural Economics*, 60(3), pp. 302–11.

Hazell, P., Jagger, P. and Knox, A. (2001) Technology, natural resource management and the poor (2000), thematic paper for (IFAD 2001).

Hazell, P. B. R., Ramasamy, C., Aiyasamy, P. K. and International Food Policy Research Institute (1991) *The Green Revolution Reconsidered: The Impact of High-yielding Rice Varieties in South India* (Baltimore: Johns Hopkins University Press).

Herring, R. J. (2007) Stealth seeds: bioproperty, biosafety, biopolitics, *Journal of Development Studies*, 43(1), pp. 130–57.

Hossain, M. (1988) *Nature and Impact of the Green Revolution in Bangladesh* (Washington, DC: International Food Policy Research Institute).

Drought-Resistant Soy In Pipeline: Monsanto scientists zero in on drought-resistant soybeans (2004) *St Louis Post-Dispatch—Knight Ridder/Tribune Business News*, 2 June, accessed at: http://www.afaa.com.au/news/news-1453.asp

Huang, J., Ruifa, H., Fan, C., Pray, C. and Rozelle, S. (2003) *Bt* cotton benefits, costs and impacts in China, Working Paper 202, Institute of Development Studies, Brighton.

International Foundation for Agricultural Development (IFAD) (2001) *Rural Poverty Report 2001* (Rome: Oxford University Press).

International Fertilizer Industry Association (2004) Fertilizer consumption, by region, 1970/71 to 2000/01, Africa (excluding Egypt and Libya), accessed at: http://www.fertilizer.org/ifa/statistics/indicators/ind_cn_afr.asp

India's foodgrain crisis and steps to meet it (1959) Agric. Production Team/Ford Fdn, Min of Agriculture, Delhi.

James, C. (2004) *Global Review of Commercialised Transgenic Crops: 2003* (Ithaca: International Service for the Acquisition of Agri-Biotech Applications).

Kerr, J. and Kohlavalli, S. (1999) Impact of agricultural research on poverty alleviation, Environment and Technology Discussion Paper No. 56, International Food Policy Research Institute, Washington, DC.

Lipton, M. (2001) Challenges to meet: food and nutrition security in the new millennium, *Proc. Nutrition Society*, 60, pp. 203–14.

Lipton, M. (2005) Crop science, poverty and the family farm in a globalising world, IFPRI 2020 Discussion Paper, Washington, DC.

Lipton, M. (1994) Food production and poverty, in B. Harriss-White and J. Hoffenberg (eds), *Food: Multidisciplinary Perspectives* (Oxford: Blackwell).

Lipton, M. (2000) Reviving global poverty reduction: what role for transgenic plants?, 19th Sir John Crawford Memorial Lecture, Washington, DC, CGIAR.

Lipton, M. with Longhurst, R. (1989) *New Seeds and Poor People* (London: Unwin Hyman).

Lipton, M. and Ravallion, M. (1995) Poverty and policy, in J. Behrman and T. N. Srinivasan (eds), *Handbook of Development Economics. Vol. 3B*, pp. 2551–657 (Amsterdam: North Holland).

Make your minds up (2004) Editorial, *Farmers' Guardian*, 2.4.

Maxwell, S. (2004) New directions for agriculture in reducing poverty, DfID Consultation Launch Document.

Nuffield Council on Bioethics (1999) *Genetically Modified Crops: The Ethical and Social Issues* (London: Nuffield Council on Bioethics).

Nuffield Council on Bioethics (2004) *The Use of Genetically Modified Crops in Developing Countries* (London: Nuffield Council on Bioethics).

Pachico, D., Escobar, Z., Rivas, L., Gottret, V. and Perez, S. (2002) Income and employment effects of transgenic herbicide-resistant cassava in Colombia: a preliminary simulation, in R. Evenson, V. Santaniello and D. Zilberman (eds), *Economic and Social Issues in Agricultural Biotechnology*, pp. 356–7 (Wallingford: CABI International).

Paine, J., Shipton, C., Chaggar, S., Howells, R., Kennedy, M., Vernon, G., Wright, S., Hinchliffe, E., Adams, J., Silverstone, A. and Drake, R. (2005) Improving the nutritional value of Golden Rice through increased pro-vitamin A content, *Nature Biotechnology*, 23, pp. 482–7 (2005) (published online: 27 March 2005, DOI: 10.1038/nbt1082).

Psacharopoulos, G. and Patrinos, H. (1993) Indigenous people and poverty in Latin America: an empirical analysis, Report No. 30, World Bank, LAC Technical Department, Regional Studies Program.

Pinstrup-Andersen, P., de Londono, N. and Hoover, E. (1976) The impact of increasing food supply on human nutrition, *American Journal of Agricultural Economics*, 58, pp. 131–42.

Qaim, M. and Zilberman, D. (2003) *Bt* cotton in India: Field-trial results and economic projections, *World Development*, 31(12), pp. 2115–27.

Ravallion, M. (2000) On the urbanisation of poverty, mimeo, World Bank, Washington, DC.

Reardon, T., Timmer, C. P. and Berdegue, J. A. (2003) The rapid rise of supermarkets in Latin America and East/Southeast Asia: implications for domestic and international markets for fruits and vegetables, in A. Regmi and M. Gehlhar (eds), *Global Markets for High Value Food Products*, Agriculture Information Bulletin, USDA–ERS.

Roy, D., Herring, R. J. and Geister, C. C. (2007) Naturalising transgenics: official seeds, loose seeds and risk in the decision matrix of Gujarati cotton farmers, *Journal of Development Studies*, 43(1), pp. 158–76.

Rosegrant, M. and Hazell, P. (1999) *Transforming the Rural Asian Economy: The Unfinished Revolution* (Hong Kong: Oxford University Press, for Asian Development Bank).

Sen, A. K. (1981) *Poverty and Famines: An Essay on Entitlement and Deprivation* (Oxford: Clarendon Press).

Sen, A. K. (2001) *Poverty and Famines: An Essay on Entitlement and Deprivation* (Oxford: Oxford University Press).

Shankar, B. and Thirtle, C. (2005) Pesticide productivity and transgenic cotton technology: the South African smallholder case, *Journal of Agricultural Economics*, 56, pp. 97–116.

Shankar, B. and Thirtle, C. (2003) Pesticide productivity with smallholder *Bt* cotton in Makathini Flats, KwaZulu-Natal, symposium paper for 25th conference of the International Association of Agricultural Economists, Durban.

Smith, L. and Urey, I. (2002) Agricultural growth and poverty reduction: a review of lessons from the post-Independence and green revolution experience in India, mimeo, Imperial College at Wye.

Strauss, J. and Thomas, D. (1995) Human resources: empirical modelling of household and family decisions, in J. Behrman and T. N. Srinivasan (eds), *Handbook of Development Economics. Vol. 3B*, pp. 1893–908 (Amsterdam: North Holland).

Sundaram, K. and Tendulkar, S. (2002) The working poor in India: employment-poverty linkages and employment policy options, Issues in Employment and Poverty series: Discussion Paper 4, International Labour Office, Geneva.

Svedberg, P. (1990) Undernutrition in sub-Saharan Africa: is there a gender bias?, *Journal of Development Studies*, 26, pp. 469–86.

Thirtle, C., Piesse, J. and Jenkins, L. (2003) Can TRANSGENICS technologies help the poor?, *World Development*, (31), pp. 717–32.

UN, ECOSOC (2005) *World Population Projections: the 2004 revision*, population database, accessed at: http://esa.un.org/unpp

World Water Council (2000) *A Water-Secure World: Vision For Water, Life and the Environment* (Marseille: World Water Vision).

Zimmermann, R. and Qaim, M. (2002) Projecting the benefits of golden rice in the Philippines, Discussion Paper on Development Policy No. 51, Bonn, Centre for Development Research ZEF.