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Induced innovation and land degradation in developing country agriculture[†]

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With few exceptions, induced innovation theories give little consideration either to the role of distortions as determinants of the factor biases of innovations, or to the influence of technical progress – with or without distortions – on the sectoral structure of production. This analysis identifies demand for innovations as a function of a specific policy setting which both conditions and is conditioned by the structure of production. In this context, when some sectors contribute more than others to environmental externalities, private and social optima in the allocation of research resources may diverge. In some circumstances it may be optimal to use research budget allocations as second-best substitutes for Pigouvian taxes.

1. Introduction

In the theory of induced innovation, the allocation of resources to the development and dissemination of new technologies is directed by relative factor scarcity, as reflected in market prices.[1] It is well known, however, that market prices need not reflect the social opportunity cost of factors, for a variety of reasons including missing markets and the existence of prior policy interventions. Distorted factor prices may generate factor or commodity biases in the demand for innovations, relative to the set of innovations that would be demanded at undistorted prices.

In this article I explore the implications of agricultural research directed at sectors that generate disproportionate levels of environmental damage,

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[1] 'a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind – directed to economising the use of a factor which has become relatively expensive' (Hicks 1964). As a long-run phenomenon the theory has considerable empirical support (Hayami and Ruttan 1985; Binswanger *et al.* 1978).

and which are also the beneficiaries of policy interventions. The primary focus is on the ways in which such distortions affect the demand for innovations by altering the sectoral structure of production and thus the pattern of relative factor returns. As the article points out, some industries demanding, and winning, research resources might not even exist but for the presence of policies or externalities; progress in R&D then has the potential to augment the commodity or factor biases that these distortions impart.

Several previous studies (for example Murphy, Furtan and Schmitz 1993; Alston and Martin 1995) have examined the interaction of trade policies and agricultural research, including the possibility that research directed towards a protected sector may have a negative rate of return when measured at shadow prices. However, this literature dwells almost exclusively on single-commodity cases and excludes factor markets (Alston and Martin's model has several commodities but focuses on the special case of a price-making exporter). This article extends earlier work in these directions, as well as incorporating externalities and a mechanism explaining the demand and supply of innovations in terms of prices and distortions. If decisions about the allocation of public research resources fail to make use of appropriate shadow prices, then the commodity and factor biases of publicly funded research (the supply of innovations, in this article) could reflect private rather than social optima and thus lead potentially to immiserizing growth. The article motivates this theoretical inquiry with a brief and informal case study from highland Southeast Asian vegetable economies.

1.1 Agricultural development and land degradation in the uplands

In addition to the usual range of staple grains and subsistence foods, highland farmers in many parts of Asia take advantage of the special characteristics offered by elevation to grow not only traditional cool-climate crops such as coffee, tea, and cacao, but – increasingly – to supply temperate-climate vegetables such as white potato, carrots, cabbage, and lettuce for sale to burgeoning urban middle classes (Hefner 1990; TDRI 1994; Lewis 1992; Librero and Rola 1994; Scott 1987).[2] Potato production in the highlands of some Southeast Asian countries provides an interesting example, since this rapidly growing industry is characterised by both environmental externalities and strong policy support.

[2] Under current technologies potato grows best in regions where night-time temperatures fall below 18°C. In Southeast Asia production usually starts at altitudes well above 500 m.

In developing Asian countries where potato is commercially grown, output growth in recent years has exceeded population growth,[3] with most of the increase apparently coming from area expansion rather than from yield increases (Librero and Rola 1994; Scott 1987). Although the area planted to this non-traditional crop is relatively small, its expansion is nevertheless highly influential since it represents a move in the most ecologically fragile areas from soil-conserving tree crops, pasture and long-fallow systems to highly intensive vegetable gardening in which frequent tillage and weeding greatly increase the exposure of soils to the leaching and eroding effects of monsoon rains. Moreover, pesticide and fertiliser use levels on vegetables are extraordinarily high. Potato in particular is very intensive in its use of labour, fertiliser and chemical inputs relative to more traditional upland crops (Coxhead 1995).

Soils in tropical uplands are typically shallow and fragile in structure, and are easily eroded once their permanent cover is disturbed or removed. However, productivity declines may be barely noticeable until the topsoil has been depleted and the infertile subsoil exposed (Lal 1990; Hoang 1994). The difficulty of measuring inherent soil quality, often coupled with inadequate definition or enforcement of property rights near the frontier of cultivation,[4] means that upland land prices seldom fully capture variation in soil quality. Similarly, off-site damages (flooding, variability of water supply, siltation and water pollution) associated with soil erosion and pesticide runoff have major impacts on other upland farms as well as on the downstream costs of providing irrigation, power generation and drinking water. However, the costs of this non-point pollution are also not capitalised into upland land values. Upland vegetable cultivation is thus widely associated with negative externalities, both on-site and further downstream.

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[3] Econometric evidence on the demand for potato in tropical countries is scarce. Librero and Rola (1995, table 2.18) cite findings from a 1973 Philippine study in which the expenditure elasticity for potato, estimated at 0.87, is by far the highest of all such elasticities in a 16-commodity study, this value is 50 per cent greater than for all but one other vegetable.

[4] Highland land is rarely held in legal title in Southeast Asia. Most highland areas are classified as public property either by virtue of their slope, or because they form part of a protected forest or watershed area. Thus in Thailand a major impediment to socially optimal agricultural land use arises because 'there is *no legal basis* supporting sustainable permanent agriculture in the highlands' (TDRI 1994; emphasis in original). In the Philippines, where all land above 18 per cent slope is officially inalienable public property, the wholesale invasion and denudation of mountain areas in the Philippines by vegetable farmers have been documented by Lewis (1992). Without secure tenure farmers are unlikely to take full account of on-site land degradation problems associated with cultivation of nutrient-depleting crops.

Table 1 Fresh vegetable and potato trade policies in some Southeast Asian countries

Country	Year	NPR: Fresh vegetables Range	NPR: Fresh vegetables Average[a]	Potato trade policies	Other relevant trade policies
Indonesia	1990	0–50%	21% (NPR) 29% (EPR)	NPR: 29% EPR: 33%	Duty-free seed potato imports
Malaysia	1993	0–5%	4.4%	None	Phytosanitary licensing; cabbage import quota
Philippines	1992	3–45%	38.1%	Import ban since 1950[b]	Seed potato import licensing
Singapore	1989	0	0	None	
Thailand	1989	2.4–94.1%	52.7%*	Import ban[c]	Seed potato import licensing

Notes: [a]Simple average except: *weighted average of applied tariffs.
[b]The 1993 Philippine law directed primarily at upland vegetable farmers and known as the 'Magna Carta for Small Farmers' (RA no. 7607) reiterated the import ban on potato, cabbage and some other horticultural crops and mandated that 'importation of agricultural commodities that are locally produced in sufficient quantities will not be allowed, to protect producers from unfair competition' (Philippine Department of Agriculture 1993, p. 31).
[c]Under Thai law, fresh potatoes are listed among restricted imports in the category of 'imports generally not allowed' with the objectives of 'protecting local production' and 'to enable farmers to sell their products at reasonable prices' (GATT 1991a, pp. 259–60).
NPR = Nominal rate of protection.
EPR = Effective rate of protection.
Sources: GATT 1991a, 1991b, 1992, 1993a, 1993b.

In Thailand, Indonesia and the Philippines, potato producers have been the target of special trade and market policies (table 1). Potato imports to these countries make up 1 per cent or less of domestic supply in most years, except in Thailand, where the figure is around 5 per cent. Domestic farm-gate prices exceed the Singapore c.i.f. price of imports from Europe, China and Taiwan by margins of 30 per cent or more, and wholesale prices in major urban markets are higher still.[5] The argument that transport costs confer 'natural' protection on potato appears weak when we observe that in Malaysia, where potato imports are in effect untaxed, there is no commercial

[5] Singapore maintains free trade in fresh potato and imports large quantities from around the world (Scott 1987). The Singapore c.i.f. price is therefore a reasonably good indicator of regional border prices. Scott (1987) observed that in the period 1979–84 farm gate prices in northern Thailand (that country's main production area) were approximately equal to the Thai currency equivalent of Singapore retail prices. In the Philippines, one of the few countries in the region for which time series of potato prices are available, the *farm gate* price exceeded the Singapore c.i.f. price by an average of 28 per cent between 1961 and 1985 (figure 1). However wholesale prices in Manila, the major market, exceed farm gate prices by 50–100 per cent or more.

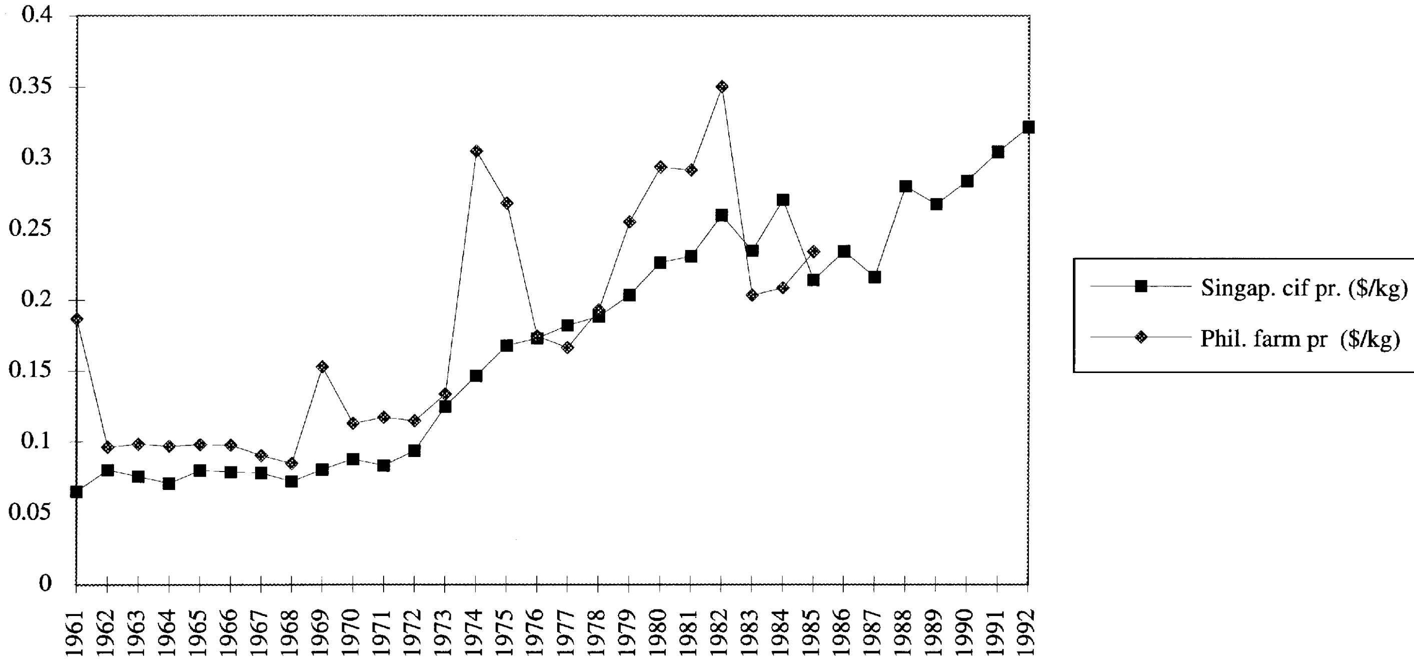

Figure 1 Potato: Philippine farm gate and Singapore c.i.f. import prices
Sources:

Philippine prices calculated from Crissman (1989), Appendix A;
Singapore prices calculated from FAO (various years).

cultivation in spite of the presence of a thriving vegetable industry in areas like the Cameron Highlands.[6]

Under current technologies it is difficult to imagine Southeast Asian potato producers competing successfully with imports under free trade – that is, at shadow prices *before* environmental costs are taken into account. The import restrictions shown in table 1 appear to be necessary conditions for the existence of this industry. In spite of this, its continued expansion enjoys strong policy support. The Philippine Department of Agriculture, for example, has designated potato, together with more traditional Philippine agricultural exports such as mango and banana, as a 'high-valued crop' targeted for special policy attention under the 'Key commercial crops development program' (Philippine Department of Agriculture 1995).[7] Highland vegetable producers in turn have formed highly focused and sometimes powerful lobby groups to defend their status and to press for public resources in providing infrastructure, marketing support and research and extension services.

Governments, aid agencies, international organisations and some private corporations are engaged in technology transfer and adaptive research directed at improving potato varietal selection, seed stocks, production techniques and pest management. Off the farm, governments and bilateral aid projects have invested in infrastructural development, marketing support, price stabilisation, input subsidies and related activities (Crissman 1989; TDRI 1994).[8] It is difficult to quantify the allocation of research resources to a specific crop, however, the limited data available from the Philippines

[6] The *FAO Production Yearbook* does not report potato production data for Malaysia; however, the *FAO Trade Yearbook* does report imports. Studies of the Malaysian vegetable economy make no mention of potato cultivation (Dagap 1987; Bin Othman 1990) and vegetable specialists working in Malaysia observe no potato production (David Midmore, personal communications).

[7] In Thailand, a range of foreign-funded projects and the government's Royal Project have been instrumental in channelling funds and resources to highland agricultural development. These projects have introduced new temperate climate fruit, flower and vegetable crops to highland areas, encouraging their adoption by subsidising adaptive research, input costs and marketing (TDRI 1994). The Thai Department of Commerce, which sets trade policy, has manipulated the quantitative restriction on seed potato imports with the aim of defending domestic potato prices, restricting imports in years of high domestic production and relaxing them in bad years (Scott 1987).

[8] Upland farmers are typically among the poorest groups in any developing country, and a case can be made on distributional and anti-poverty grounds for discriminating in their favour. However, this is not generally true for commercial vegetable farmers. According to Crissman (1989, p. 9): 'Potato production in the Philippines is a highly profitable activity: potato producers in Benguet [the major growing area] are among the wealthier small farmers in the country.'

indicate that in that country, the share of vegetables, legumes and root crops in agricultural R&D is approximately equal to their share of the total value of agricultural production at market prices, while the R&D share of more land-intensive plantation crops (coffee, cacao, rubber) that compete for upland land and labour resources is only about one-fifth of their share in the value of production (figure 2). The volume of research output on a commodity provides another indicator of its share of R&D resources. Librero and Rola (1994) reviewed 182 research papers produced in the Philippines between 1970 and 1993 that studied production, marketing and consumption of vegetables. Of these, 38 (20 per cent) addressed white potato in whole or in part – a fraction far exceeding the importance of this crop among all vegetables produced in the country. Similar ratios were reported for other highland vegetables, such as cabbage, also covered by import bans or restrictions.

In summary, many economic and environmental signals point to Southeast Asia's potato industry as one in which private returns substantially exceed social profitability. In this article I examine mechanisms by which such an industry might become established and grow, and ask how policy-makers should respond in the allocation of agricultural research resources. I focus on both trade policies and unaccounted environmental costs as the sources of differences between market and shadow prices. These distortions are shown to be capable not only of altering the structure of upland production – for example, making it profitable to begin cultivation of some crop – but also of spawning demands for R&D investments that may themselves reinforce the distorted structure.

In the next section I present a simple model examining the effects of distortions and technical progress on the structure of production. In the subsequent sections I speculate on the likely welfare and environmental outcomes when a distorted industry structure generates biases in the demand for new technologies. A necessary condition for these to compound the effects of the original distortions is that the supply of innovations be responsive to distorted rather than shadow prices. The article concludes with some observations on this point and a discussion of implications for a medium-run theory of induced innovation.

2. Prices, production and land degradation

How do commodity price interventions, factor endowment changes and technical progress alter the structure of production in a price-taking economy? How do such changes affect the endogenous depletion of a resource such as land quality? In this section I explore these questions and evaluate their welfare implications. I use a static, two-factor, two-good

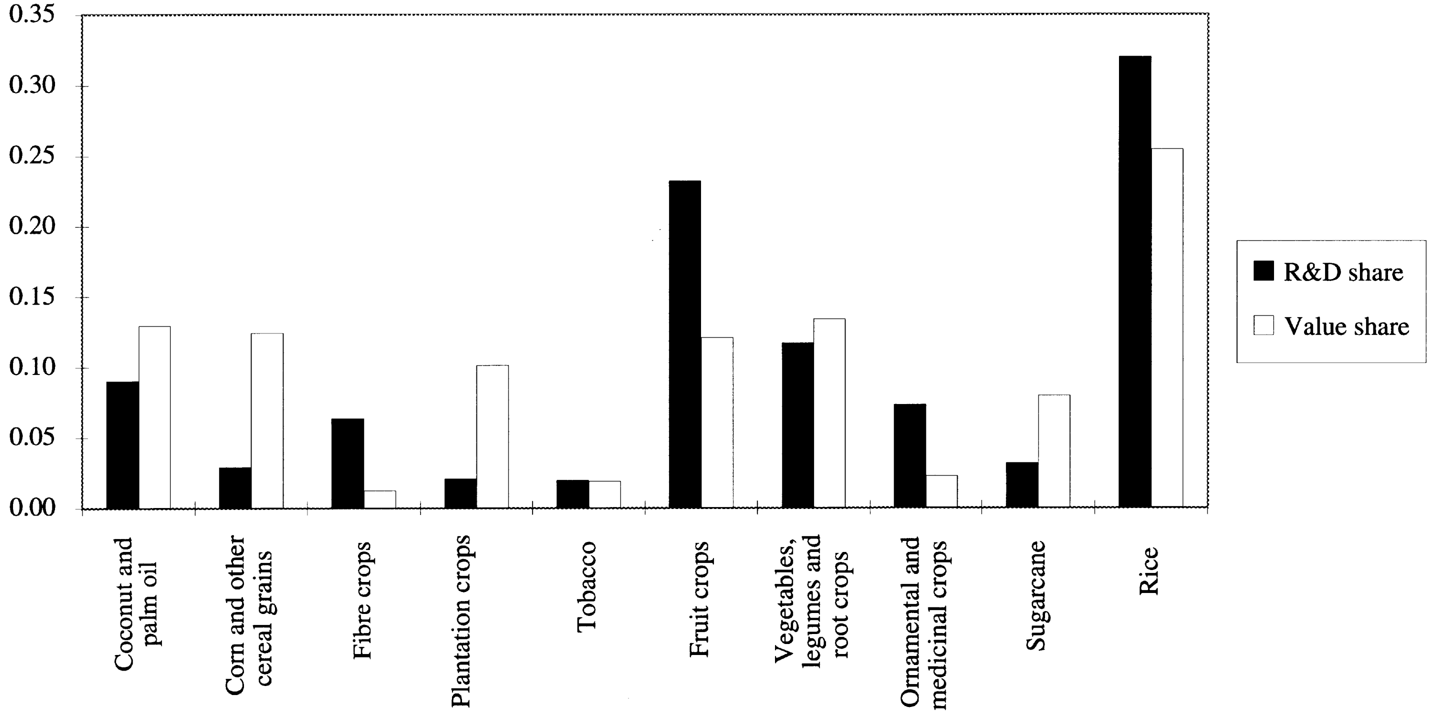

Figure 2 Commodity shares in agricultural R&D expenditures and the value of agricultural production, Philippines
Sources: (R&D shares) Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development; (Value shares) NCSO 1993.

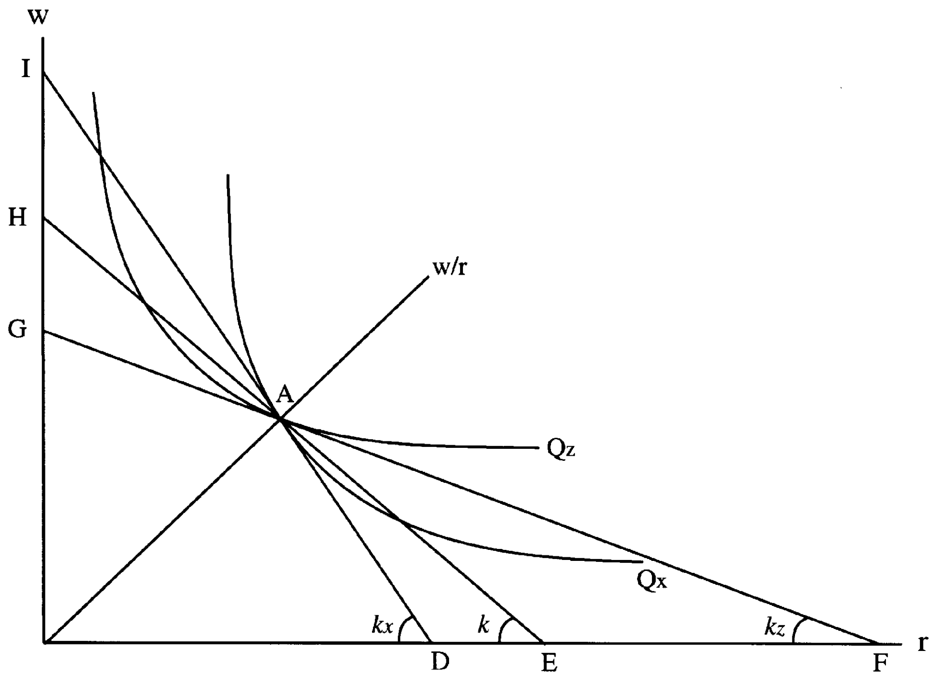

Figure 3 Endowments, technology and the structure of production

partial equilibrium framework to highlight the role of equilibrium conditions and to examine the role of price policy interventions and technical progress as factors conditioning the rate of land degradation. In this section technical progress is assumed to occur exogenously; in a subsequent section I relax this restriction in order to examine the market for R&D and the innovation inducement mechanism.

Consider an upland agricultural economy in which two goods, X and Z, can potentially be produced using fixed endowments of land (K) and labour (L). Prices (p_x and p_z) are set in an external market and these in turn determine wages (w) and returns to land (r).[9] We are particularly interested in the structure of production and how it is influenced by product prices, factor endowments, and technical progress. Figure 3 presents the basic

[9] The return to labour should be interpreted as a return not only to the 'raw' input (for which the long-run price could seldom be argued to be endogenous to an agricultural region, even with positive transactions costs) but rather to labour plus management inputs. In the upland setting, farms typically consist of many small plots worked mainly by family labour; their managerial input is substantial.

model.[10] Revenues in each sector are exhausted in factor payments, so for each good there is a family of isoprofit curves $Q_j(p_j)$, showing the factor price combinations consistent with zero pure profits for given technology and output price:

$$Q_j = p_j y_j - wL_j + rK_j = 0, \quad j = X, Z, \tag{1}$$

where $y_z = Z$ and $y_x = X$. The shape of an isoprofit curve indicates the value of the elasticity of factor substitution in the technology used to produce that good, and the absolute value of the slope of each curve shows the land–labour ratio consistent with zero pure profits at that point. As drawn, production consists of a land-intensive good (X) and a labour-intensive good (Z).

A ray from the origin through point A, at the intersection of Q_z and Q_x, shows the market-clearing factor price ratio, w/r. Lines tangent to each isoprofit curve at this point have slopes equal to the negative of the equilibrium sectoral labour–land ratios k_x and k_z. Both goods will be produced in equilibrium only if the economy's aggregate land–labour ratio is of intermediate slope. An example of such a ratio is given in the diagram by the line with slope k, where $k_x > k > k_z$. If k lies outside this range the economy will specialise in production of either X or Z. The condition that $k_x > k > k_z$ is equivalent to the requirement that the endowment point lie within the 'cone of diversification' – the region in which at least as many goods are produced as factors used in their production (Woodland 1982).

In this model, the representative producer's goal is to minimise costs over the domain in which profits are non-negative. This domain is defined by the area above both isoprofit curves, so given an initial endowment ratio k, the equilibrium is at A. This equilibrium is altered by changes in endowments, commodity prices or technology.

An increase in the endowment of labour relative to land is shown in figure 4 as a shift in the aggregate land–labour ratio from HE to $H'E'$. The endowment change reduces k, but as long as it is sufficiently small that $k_z < k < k_x$ continues to hold, the factor market equilibrium remains at A and factor prices are unchanged. Instead, labour endowment growth causes a change in the sectoral structure of production. This can be seen in figure 4 by defining employment shares $\lambda_{lj} = L_j/L$ for $j = X, Z$ and noting that along

[10] This exposition uses the dual of the usual isoquant diagram in order to highlight changes in the structure of production. For earlier presentations of this dual model see Dixit and Norman 1980; Woodland 1982 and Mussa 1979. Production technology is assumed to be non-joint and to exhibit constant returns to scale.

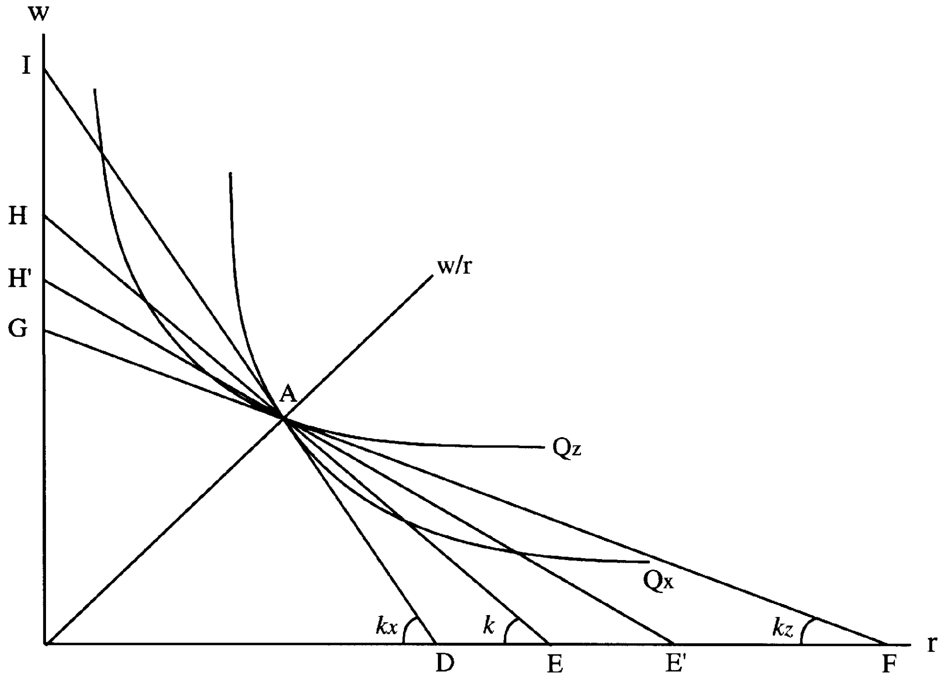

Figure 4 Effects of a rise in the labour–land endowment ratio

the vertical axis $\lambda_{lx} = GH/GI$ and $\lambda_{lz} = HI/GI$.[11] The decline in k thus reduces λ_{lx} and increases λ_{lz}; since factor ratios in each sector are unchanged at constant factor prices, output of Z must rise and that of X fall (the Rybczinski effect). Specialization in Z (or X) will occur in an initially diversified economy only if the change in the k is large enough that $k \geq k_z$ (or $k \leq k_x$).

Commodity price rises displace the isoprofit curves outwards from the origin. Figure 5 shows this for a rise in p_z, which shifts the isoprofit curve for that sector to Q'_z; this results in a new factor market equilibrium at B. The

[11] Land is fully employed in production, so

$$K_x + K_z = K, \text{ from which}$$
$$\lambda_{lx}k_x + \lambda_{lz}k_z = k,$$

but

$$\lambda_{lz} = 1 - \lambda_{lx}; \text{ rearranging terms:}$$
$$\lambda_{lx} = (k_z - k)/(k_z - k_x) = HI/GI, \text{ and } \lambda_{lz} = (k - k_x)/(k_z - k_x) = GH/GI.$$

Figure 4 shows a decline in the land–labour ratio, so $k' < k$: then $\lambda'_{lx} > \lambda_{lx}$ and $\lambda'_{lz} < \lambda_{lz}$. Since the labour stock is fixed and factor prices are unchanged, the output of Z must have risen and that of X declined at the new land–labour ratio (adapted from Mussa 1979).

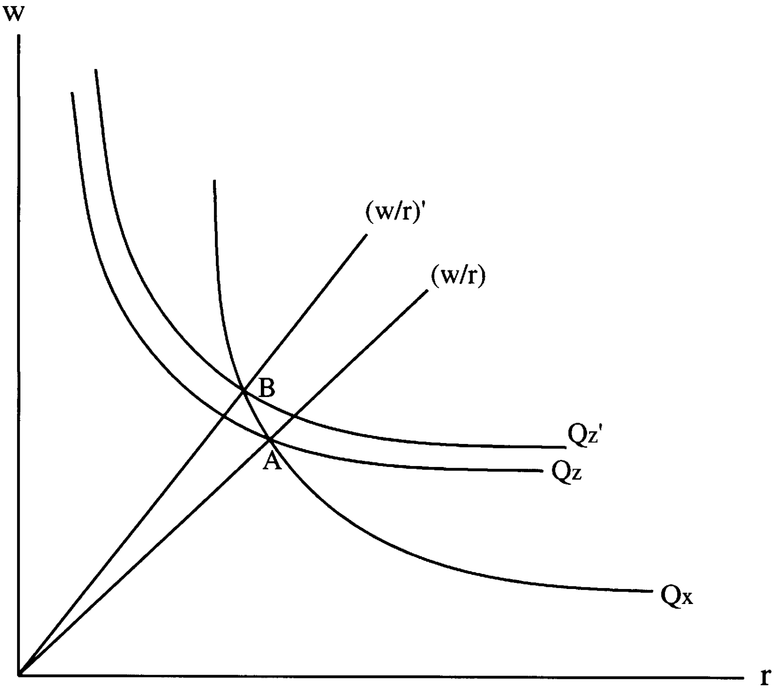

Figure 5 Effects of a rise in P_z relative to P_x

structure of production also changes; this can be read in the same way as for figure 4 from changes in factor employment shares. Both sectors become more land-intensive, but the shares of sector Z in employment of both capital and labour rise while those of sector X fall. The sector whose price has risen has thus expanded, and the other contracted – the Stolper–Samuelson result. The price change also leads to a new factor market equilibrium, in which the price of the factor used relatively intensively by the expanding sector increases relative to that of the other factor; thus at B, $(w/r)' > (w/r)$.

Technical progress in either sector allows producers to pay more for factors and still make zero pure profits; therefore, it too can be represented as an upward displacement of the relevant isoprofit curve (in the special case of factor-neutral technical progress, the displacement is homothetic and thus identical to that caused by a price change and shown in figure 5). For given commodity prices, output of the sector experiencing technical progress increases and that of the lagging sector declines.

It follows from the relationships shown in figure 5 that price and technology policies play potentially important roles in determining the structure of production. Price policy or R&D resources may be deployed in ways designed to generate substantial changes in factor allocation and the output mix. In fact – and this is a point generally obscured by the factor market focus of the induced innovation literature – price or technology changes, by shifting the cone of diversification, can induce an economy that was specialised in a single sector to diversify, or conversely, induce specialisation in a formerly diversified economy.

2.1 Structure of production and land degradation

In upland areas of developing countries, agricultural land degradation rates depend critically on land use. Some crops and technologies cause much more rapid rates of soil nutrient depletion and erosion than others (Lal 1990). Therefore, when land is reallocated among upland agricultural sectors, the rate of change of average land quality and of the amount of erosion produced is likely to be altered. We can incorporate the effects of land use on land quality in this model by measuring factor quantities in effective rather than in physical units. Thus a change in land quality is the same as a change in the effective land endowment, and the geometric analysis of such a change is exactly as shown in figure 4 for an equivalent change in physical endowments. Small changes in the effective endowment are not reflected in factor prices; instead, the structure of upland production shifts in the direction of the sector making more intensive use of the factor whose effective endowment has grown by more. The difference between the two cases lies in the welfare interpretation when the effective endowment change is not given its full value – as will be discussed below.

In the next subsection we formally link the structure of upland production to the rate of land degradation. Before doing so it is helpful to identify conditions under which price or technology changes have different implications for the value of output, economic welfare and policy. Relative sector size and factor intensity are clearly important, but in addition we need to know which activity is more land-degrading on a per-hectare basis, since the more land-intensive technology need not be more land-degrading (and in fact is rarely so).

If a sector is relatively land-intensive (as with X in the figures), and if technology in that sector is also more land-degrading, some or all of the expansion of its output (whether due to technical progress or a favourable price shift) will be cancelled by the endogenous reduction in the effective land endowment as average land quality declines. The endowment shift will have the opposite effect of causing the X sector to contract. Alternatively, if the land-intensive sector is relatively less land-degrading, then its expansion due to a price or technology shift will be reinforced by the rise in the effective land–labour ratio as resources are drawn out from the more land-degrading sector. A third case is paradoxical: if the expanding sector is relatively labour-intensive but is more land-degrading on a per-hectare basis, its relative profitability will be *reinforced* by the effective land endowment decline that its expansion brings about.

Analytically, the third case is clearly the most interesting since it embodies the greatest potential for welfare losses. Empirically, this is also the most commonly observed case in the uplands of developing countries. Grain and vegetable crop production technologies in such regions are typically far more intensive in their use of non-land inputs than are perennial crops; moreover, seasonal crops are associated with higher levels of land degradation and soil erosion than are perennials. The third case also holds the greatest policy interest since developing country trade, price and research policy differences between perennials (mainly exportables) and grain or vegetable crops (typically importables) are often very great, as indicated earlier.

Consider the effects of a tariff or equivalent price support conferred on Z when that sector is both labour-intensive and land-degrading relative to X. The tariff causes Z to expand and X to contract, as in figure 5. The fraction of total land used in Z increases and, in addition, both sectors become more land-intensive. Both components of the shift cause the average rate of land degradation to increase, giving rise to an effective endowment change like the one shown in figure 4, favouring increased production of the less land-intensive crop.

However, for a small change in the effective land endowment there will be no change in factor prices, as figure 4 showed: in other words, the effects of land degradation will not be capitalised into land prices. In this case, therefore, both the price intervention and unaccounted environmental damage promote increased production in the land-degrading sector.

2.2 Welfare implications of distortions and externalities

If increased land use in sector Z causes a decline in the effective land endowment, then the decline should be captured in a measure of the welfare implications of policies supporting that sector's expansion, even if market prices do not change. In this section we construct such a measure, assessing the effects of a tariff change on real expenditures by analysing the aggregate budget constraint (sometimes called a trade expenditure function). In an economy with one initial distortion – a tariff on good Z – and an externality in the form of a missing market for land quality, the aggregate budget constraint may be written as:

$$e(\mathbf{p}, u) = g(\mathbf{p}, \mathbf{v}, \tau) + t_z[e_z(\mathbf{p}, u) - g_z(\mathbf{p}, \mathbf{v}, \tau)] - s(\alpha_x K_x, \alpha_z K_z), \tag{2}$$

where $e(\mathbf{p}, u)$ is the expenditure function of the representative consumer in prices $\mathbf{p} = (p_x, p_z)$ and utility; $g(\mathbf{p}, \mathbf{v}, \tau)$ is the economy's aggregate revenue function in $\mathbf{p}$, factor endowments $\mathbf{v} = (K, L)$, and technology $\tau = (\tau_x, \tau_z)$. By Shephard's lemma the partial derivatives of $e(\cdot)$ and $g(\cdot)$ with respect to p_z, denoted by e_z and g_z respectively, are functions describing domestic demand and supply for Z. The initial tariff on Z is $t_z = (p_z - p_z^*)$, where p_z^* is the foreign (border) price; and $s(\cdot)$ is a damage function in sectoral unit damages $\alpha_j (\geq 0)$ and land use K_j.[12] Privately optimal sectoral factor demands are obtained by cost minimisation as $K_j = \partial c^j(\mathbf{w}, y_j)/\partial r$, evaluated at $r(\mathbf{p}, \mathbf{v}) = \partial g(\mathbf{p}, \mathbf{v})/\partial K$, $w(\mathbf{p}, \mathbf{v}) = \partial g(\mathbf{p}, \mathbf{v})/\partial L$, and $y_j(\mathbf{p}, \mathbf{v})$ for $j = X, Z$. Combining these provides an expanded description of the damage function in terms of prices, tariffs, endowments, technical progress and sector-specific rates of land degradation:

$$s(\alpha_x K_x, \alpha_z K_z) = s(\alpha_z y_z c_r^z(\mathbf{w}), \alpha_x y_x c_r^x(\mathbf{w})). \tag{3}$$

What are the welfare implications of an increase in protection for producers in sector Z? We can answer this question by taking the total derivative of (2) with respect to p_z, using (3), noting that $dp_z = dp_z^* + dt_z$ and setting $dp_z^* = 0$. After some manipulation we have:

$$\gamma(du/dt_z) = t_z(e_{zz} - g_{zz}) + \partial s/\partial t_z, \tag{4}$$

where $\gamma = (1 - t_z e_z p_z^*) > 0$, and $e_{zz} < 0, g_{zz} > 0$ are the second partial derivatives of $e(\cdot)$ and $g(\cdot)$ with respect to p_z. The 'pure' trade policy result $(\partial s/\partial t_z = 0)$ is well known: an increase in the rate of the tariff reduces welfare, exclusive of environmental effects, by inducing overproduction and underconsumption of Z relative to free trade prices (e.g. Vousden 1990).

Evaluating the change in $s(\cdot)$ is less straightforward. Taking the derivative of (3) with respect to p_z (and noting that $dp_z = dt_z$ when $dp_z^* = 0$):

$$\partial s/\partial t_z = \sum_j \alpha_j c_r^j(\mathbf{w})(\partial y_j/\partial p_z) + \sum_j \alpha_j y_j c_{rr}^j(\partial r/\partial p_z) + \sum_j \alpha_j y_j c_{rw}^j(\partial w/\partial p_z). \tag{5}$$

The total change in the damage function has one component reflecting changes in the structure of factor demand at constant factor prices, and two

[12] Land degradation occurs over long periods and its rate can be influenced by input and technology decisions. As such it is customary to model land quality as a state variable in a dynamic optimisation problem (for a survey see Miranowski and Cochrane 1993). In such problems other influences not included in equation (2) are important: initial soil depth and quality; regeneration rates and returns to soil-conserving investments; discount rates, expectations and risk (McConnell 1983; Clarke 1992). Use of a static model is appropriate either when discount rates are very high, or when secure property rights are absent. As documented in an earlier section and in footnote 4, property rights in upland agriculture are often poorly defined or enforced and even when markets for upland land exist, soil erosion losses may not be capitalised into land values due to the problem of measuring land quality.

others reflecting factor substitution as $\mathbf{w}$ adjusts. We can simplify the latter by noting that c_i^j is homogeneous of degree zero in $\mathbf{w}$ and making use of the Euler relation

$$wc_{rw}^j + rc_{rr}^j = 0$$

to obtain:

$$\partial s/\partial t_z = \sum_j \alpha_j c_r^j(\mathbf{w})(\partial y_j/\partial p_z) - \sum_j \alpha_j y_j c_{rw}^j[(w/r)(\partial r/\partial p_z) - (\partial w/\partial p_z)](j = X, Z). \tag{6}$$

The first term on the right-hand side of (6) confirms that when the price of one good rises in terms of the other, the output of that sector expands and that of the other sector contracts (cross-price derivatives are always negative in the two-sector model). The second term reminds us that the price change also raises the relative price of the factor used intensively in the expanding sector. When Z is labour-intensive this term is positive; the factor price change causes *both* sectors to become more intensive in the use of the relatively less expensive factor. Referring to figure 5, a rise in p_z causes the labour-intensive sector to expand – drawing in more land and labour from sector X – but also raises the factor price ratio from (w/r) to $(w/r)'$. At the new equilibrium, both sectors display higher land–labour ratios than at A.

Equation (6) shows that for a given commodity price change, the change in the damage function depends on each sector's propensity for land degradation (α_j) as well as on its relative factor intensity and the substitutability of land for labour as reflected in the cross-price derivatives c_{rw}^j. In the case of a higher tariff for a relatively labour-intensive sector with high land degradation potential, we see that $\partial s/\partial t_z > 0$, since $(\partial r/\partial p_z) < 0$, $(\partial w/\partial p_z) > 0$ and $\alpha_z > \alpha_x$. The expansion of the relatively land-degrading sector increases its land use at constant factor prices, but also raises w/r, causing producers in the expanding sector to substitute further towards land – and thus further increasing the extent of new land degradation.[13] Substituting (6) into (4), we conclude that an increase in protection for the labour-intensive, land-degrading sector will reduce aggregate welfare since the consequent increase in land degradation will augment the increased deadweight losses associated with the trade policy change.

In spite of the aggregate welfare loss, however, the tariff increase will yield private benefits to upland producers so long as any increase in on-site land degradation is not so great as to induce specialisation and thus itself to be a

[13] If Z were land-intensive, a rise in its price would raise r and reduce w, so the signed term in (6) enclosed in square brackets would be negative: factor substitution effects would diminish the additional land degradation caused by the expansion of sector Z.

source of altered factor prices.[14] The increase in protection thus benefits upland producers at the expense of the rest of the economy – including those sectors directly affected by consequent increases in off-site damages.

Finally in this section we consider the effects of technical progress. For simplicity we restrict our attention to the case of Hicks-neutral (product-augmenting) change.[15] In this form, technical change has the same effect on producers as a price rise, and indeed can be analysed by examining changes in 'effective' producer prices $\mathbf{p}\tau$, where τ is an augmentation parameter with an initial value of unity. Again starting from the equilibrium condition for a tariff-distorted economy, we consider the effects of technical progress in the Z sector. The initial equilibrium is given by:

$$e(\mathbf{p}, u) = g(\mathbf{p}\tau, \mathbf{v}) + t_z[(e_z(\mathbf{p}, u) - g_z(\mathbf{p}\tau, \mathbf{v})] - s(\alpha_x K_x, \alpha_z K_z). \tag{7}$$

Taking the total differential of this with respect to t_z gives:[16]

$$\gamma(du/d\tau_z) = p_z y_z - t_z[y_z + p_z(\partial y_z/\partial p_z)] - \partial s/\partial \tau_z. \tag{8}$$

On the right-hand side of (8), the first term is the output enhancement effect, and the second the reduction in tariff revenues attributable to the increase in Z sector output. The sum of these two terms is positive for all plausible tariff rates.[17] The third term, equivalent to that developed earlier, is the effect of technical progress on the production of the externality:

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[14] As figure 4 shows, a small change in factor endowments alters the structure of production but not factor rewards. In these circumstances the tariff increase raises total upland factor income, as can be seen by summing equation (1) over X and Z at shadow prices $\mathbf{p}^*$ and at distorted prices $\mathbf{p} = (p_x^*, p_z^* + t_z)$, $t_z > 0$, then taking the difference:

$$p_x^* X + p_z^* Z = w(\mathbf{p}^*)L + r(\mathbf{p}^*)K < p_x^* X + (p_z^* + t_z)Z$$
$$\Rightarrow \quad t_z Z = [w(\mathbf{p}) - w(\mathbf{p}^*)]L + [r(\mathbf{p}) - r(\mathbf{p}^*)]K > 0.$$

[15] The analysis is readily extended to non-neutral cases including factor-biased technical progress (Dixit and Norman 1980). Geometrically, a labour (land) saving bias in technical progress would rotate an isoprofit curve clockwise (anticlockwise) in addition to shifting it out from the origin.

[16] The derivation uses two relations that hold for product-augmenting technical progress:

$$\tau_i(\partial g/\partial \tau_i) = p_i(\partial g/\partial p_i), \text{ and}$$
$$\tau_i(\partial^2 g/\partial \tau_i \partial p_j) = \delta_{ij}(\partial g/\partial p_i) + p_i(\partial^2 g/\partial p_i \partial p_j),$$

where δ_{ij} is the Kronecker delta, i.e. $\delta_{ij} = 1$ for $i = j$, and 0 otherwise (Dixit and Norman 1980, p. 138).

[17] In Alston and Martin (1995) the possibility of immiserizing growth from technical progress depends on the magnitude of the change in this sum relative to that of the technical progress shock.

$$\partial s/\partial\tau_z = \sum_j \alpha_j c_r^j(\mathbf{w})[\delta_{jz}y_j + p_j(\partial y_j/\partial p_z)] - \sum_j \alpha_j y_j c_{rw}^j[(w/r)(\partial r/\partial p_z) - (\partial w/\partial p_z)], \tag{9}$$

where $\delta_{jz} = 1$ for $j = Z$ and 0 otherwise. The first summation on the right-hand side of (9) is positive. The second is negative when Z is relatively labour-intensive, so subtracting it has a positive effect on $\partial s/\partial\tau_z$.

Combining (9) and (8) we see that the overall welfare effect of technical progress in the labour-intensive, land-degrading sector is indeterminate. Productivity measured in terms of physical inputs is higher, but the expansion of this sector is likely to lead to increased production of environmental damage and in addition, some tariff revenues are lost as domestic output growth replaces imports. As in the case of a tariff increase, however, upland producers benefit from the technical progress since they do not suffer directly as the result of either reduced tariff revenues or a small increase in land degradation. All things being equal, we would expect that in this situation private producers will press for the development of new technologies in protected sectors even though the contribution of such innovations to increases in aggregate economic welfare is by no means assured.

3. Technical progress and the demand for innovations

In the theory of induced innovation, the demand for technical progress of a particular rate and factor-saving bias is explained in terms of shifts in factor prices or resource endowments (Hicks 1964; Ahmad 1966; Hayami and Ruttan 1985). The supply of innovations is characterised as being produced by advances in science and technology that shift out both the frontier of scientific knowledge and the 'metaproduction function' – the latter defined by Binswanger *et al.* (1978, p. 5) as 'the set of techniques that have actually been developed in the most advanced countries and that are used by the most advanced firms'. Both the demand and supply shifts are thus driven by inherently long-run phenomena. However, the theory also recognises a shorter-run innovation supply response in which changing factor endowments or prices guide the pace and direction less of basic science than of technology transfer, screening and adaptive research. These are the primary activities of most developing-country national agricultural research institutes (Binswanger and Evenson 1978; Evenson and Pray 1991).

What the theory lacks, however, is a comprehensive explanation of the demand for innovations over the same intermediate time frame: long enough for demand to be articulated and a supply response engendered, yet not so long that the influence of factor endowment trends swamps all other economic signals.[18] In less than the very long run, product price interventions and externalities could well dominate factor endowment trends in shaping the demand and even the supply of technology transfer and adaptive research. In this section we explore the mechanisms and implications of such a process.

In induced innovation theory, innovations are sought when factor price changes reflecting endowment shifts render some existing technologies unprofitable, at given output prices. In the dual formulation, factor prices within the cone of diversification are determined by product prices, and the search by producers for new technologies is directed at maximising factor returns for given output prices. This fits with the characterisation of both land and labour as fixed assets in uplands: at given product prices, innovations increase scarcity rents.

To analyse the demand for innovations we introduce *a factor price possibility frontier* (FPPF), which by definition is the dual to the metaproduction function in factor quantity space. For given commodity prices, this frontier represents the outer boundary of possible factor price vectors achievable at zero profits with a fixed research budget. The shape and slope of the frontier depend on the initial technologies (Q_x and Q_z in figures 3–5), the state of scientific knowledge, and the costs of transferring technologies to the home country or region.[19] The FPPF, or sections of it, can thus be shifted out not only by the generation of new technologies and/or reductions in the costs of their acquisition, but also by commodity price increases.

Suppose for heuristic purposes that initial innovation possibilities are neutral with respect to crops and technologies, so an equal increase in private profitability could be obtained for either crop from a given investment of research resources, R. (In this special case the shape and slope of the FPPF are determined by existing isocost frontiers, and the costs of adaptive research merely determine the radial distance between these frontiers and the FPPF.) In figure 6 the FPPF corresponding to this assumption is drawn in as $F_0(\mathbf{p}, \tau, R)$, the lower envelope passing through point C. Unlike the more general shape of the envelope typically used to represent a metaproduction function, the peaked shape of the FPPF is a reminder that much applied and adaptive research is commodity-specific rather than directly oriented to the

[18] De Janvry (1978) pointed the way for this analysis in an important article in which structural factor market distortions associated with a bimodal farm size distribution were identified as sources of socially suboptimal biases in the demand for new technologies in Argentine agriculture.

[19] Binswanger and Evenson (1978, chapter 6) provide a detailed disaggregation of the costs of adaptive research.

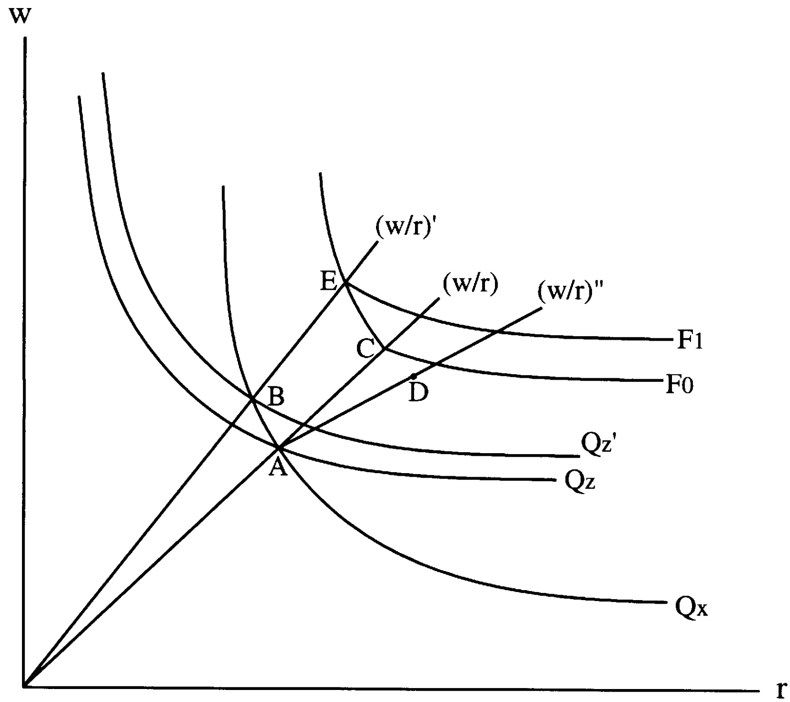

Figure 6 Factor price possibility frontiers with and without a tariff

longer-run goal of conserving a factor that has become relatively scarce. However, the FPPF also reflects the lower cost of acquiring and adapting new technologies that use factors in similar proportions to existing technologies, since the shortest path (least cost) to the frontier from any point like A is along a ray of constant factor prices. By construction, if the entire research budget were to be devoted to factor-neutral improvements in production technology for each sector, the economy could move along a ray through the origin from its initial equilibrium to the corresponding point along F_0. A shift from A to C in figure 6 is one example. Research of value R producing technologies with different factor proportions relative to A – an expansion along a ray other than w/r – could only buy a point closer to the origin than the frontier F_0.

Now suppose as before that expansion of the Z sector causes a land use shift that reduces land quality and increases environmental externalities. Technical progress in Z thus causes an increase in the production of externalities. Upland producers' incomes are unaffected by small changes in these externalities; however, aggregate welfare, which includes the costs of pollution and/or resource depletion, is a declining function of K_z. Thus to a social planner the benefits of investing in R&D directed at sector Z are lower than from the point of view of the owners of upland land and labour. How will R be allocated at market prices, and how might it be allocated by a mechanism that took distortions into account?

Since the owners of upland factors assign no value to tariff revenues or externalities, it is clear that if innovation possibilities are neutral, the optimal choice of new technology subject to a research budget constraint R will be that which moves them as far as possible along a ray from the origin. In terms of figure 6, they will always choose to move to C from A.

The social planner must take account of distortions that drive wedges between market and shadow prices. Since in this simple model all goods are traded and their undistorted prices exogenous, the social planner's optimisation problem is to choose the vector τ that maximises the value of production at shadow (border) prices, net of the effective factor endowment effects of land degradation:

$$\max(\tau_x, \tau_z)\{p_x^* X + p_z^* Z - s(\alpha_x K_x, \alpha_z K_z)\},$$

subject to $R = \tau_x + \tau_z$. A formal statement of the problem is given by the Lagrangian:

$$L = \max_{\tau_x, \tau_z, \theta}\left\{\sum_j p_j g_j(\tau\mathbf{p}, \mathbf{v}) - t_z g_z(\tau\mathbf{p}, \mathbf{v}) - s(\alpha_x K_x, \alpha_z k_z) + \theta(R - \tau_x - \tau_z)\right\}, \quad (10)$$

where $j = X, Z$ and θ is the Lagrange multiplier associated with the research budget constraint. Without loss of generality let $p_x^* = 1$. The first-order conditions of this maximisation are:

$$(\partial g_x/\partial\tau_x) + p_z(\partial g_z/\partial\tau_x) - t_z(\partial g_z/\partial\tau_x) - (\partial s/\partial\tau_x) - \theta = 0 \quad (11.1)$$

$$(\partial g_x/\partial\tau_z) + p_z(\partial g_z/\partial\tau_z) - t_z(\partial g_z/\partial\tau_z) - (\partial s/\partial\tau_z) - \theta = 0 \quad (11.2)$$

$$R - \tau_x - \tau_z = 0 \quad (11.3)$$

Combining (11.1) and (11.2):

$$[(\partial g_x/\partial\tau_x) - (\partial g_x/\partial\tau_z)] + (p_z - t_z)[(\partial g_z/\partial\tau_x) - (\partial g_z/\partial\tau_z)] = (\partial s/\partial\tau_x) - (\partial s/\partial\tau_z).$$

Using (9) and the relations provided in footnote 8, multiplying by τ_z and rearranging:

$$(\tau_z/\tau_x)[(y_x + (\partial y_x/\partial p_x)] - p_z[(y_z + p_z(\partial y_z/\partial p_z)] \\ - p_z[1 - (\tau_z/\tau_x)(1 - (t_z/p_z))](\partial y_x/\partial p_z) = (\tau_z/\tau_x)(\partial s/\partial\tau_x) - (\partial s/\partial\tau_z);$$

from which the optimal share of sector Z in the public sector R&D budget can be solved as:

$$\frac{\tau_z^*}{R - \tau_z^*} = \frac{(p_z - t_z)[(y_z + p_z(\partial y_z/\partial p_z)] + p_z(\partial y_x/\partial p_z) - (\partial s/\partial \tau_z)}{[(y_x + (\partial y_x/\partial p_x)] + p_z[1 - (t_z/p_z)](\partial y_x/\partial p_z) - (\partial s/\partial \tau_x)} \quad (12)$$

where each $\partial s/\partial \tau_j$ depends on α and price changes as in (9).

If there are no land degradation effects (e.g. if all $\alpha_j = 0$) and no initial tariff distortions ($t_z = 0$), then the socially optimal share of R&D expenditures on sector Z depends only on relative supply responsiveness and the effects of one sector's expansion on the output of the other – effects captured by the first two terms of the numerator and denominator of (12). Owners of upland factors will demand a research budget in which $\tau_z/(R - \tau_z)$ matches this ratio, and this will also be the socially optimal research portfolio.

By contrast, if some $\alpha_j > 0$ then the optimal ratio is reduced by the extent to which, other things equal, a transfer of resources from X to Z or an expansion of Z would lead to a more rapid rate of degradation – just as in the discussion of price policies and technical progress in the previous section. In the example we have been using thus far, expansion of Z reduces the effective land endowment. In figure 6, as technical progress shifts the economy closer to F_0 along w/r, the slope of the aggregate factor endowment ratio k declines in proportion to the expansion of Z. Accordingly, the social planner will prefer a different portfolio of research projects to that demanded – perhaps even one specialised in sector X technologies, but in any case having a lower allocation of resources to τ_z than that demanded by upland farmers. Thus the social planner would prefer to fund research that moves the upland economy along a ray from A of lower slope than (w/r), reflecting the higher social opportunity cost of land measured in effective units, in the direction of a point such as D, below C and also by necessity below F_0, since to acquire new technologies having different factor proportions is more costly.

Now consider the influence of the tariff on the demand for commodity-specific research resource allocation. Suppose that producers of Z have acquired additional trade policy protection, such that their isoprofit curve is initially Q_x' rather than Q_z and the initial equilibrium is at B, where (relative to A) a greater share of land is used in the land-degrading sector and production is more land-intensive in both sectors. The tariff also moves the relevant section of the FPPF out by the same proportion by which Q_z was displaced; the new FPPF is labelled $F_1(\mathbf{p} + \mathbf{t}, \tau, R)$. Upland producers will now demand a research portfolio directed to achieving the maximum factor price vector at E. However, from (12), the social planner's optimum will again lie below the privately optimal point, and in fact will diverge even further from the private optimum than in the no-tariff case. Therefore, the trade policy will have generated a commodity bias in the demand for innovations which augments that generated by the missing market for land quality, with a correspondingly greater (negative) welfare impact. If the SP's only policy instrument is the choice of τ, overproduction in Z might be offset by a compensating bias in the allocation of research resources to sector X.[20]

Before turning to a brief discussion of the policy implications of this result, we should make note of some qualifications related to some simplifying assumptions. First, non-neutral technical progress opportunities would change the above analysis in predictable ways. Inherent commodity (or factor) biases in research would be reflected in the shape of the FPPF. These would then either augment or offset other influences on the sectoral structure of production. Second, it should be noted that a sufficiently large bias in R&D resource allocation against Z may result in the upland economy specialising in the production of X. This simply mirrors the point made earlier, that price policy or commodity bias in research resource allocation could induce diversification in a previously specialised economy. If production of Z was not privately optimal before the tariff, then it is conceivable that welfare maximisation would result in denying the sector research resources to the point where production of Z ceases once again.

3.1 Innovation biases and constraints to optimal R&D allocations

The idea that research resources should be allocated in ways that compensate for distortionary policies or for environmental externalities may seem counter-intuitive at first, but in certain contexts it may be a useful and even powerful tool of agricultural development policy. In developing countries, the kinds of distortions dealt with in this article – commodity-specific trade policies and environmental externalities – are frequently very difficult to address directly. Trade policies on upland crops are particularly problematic from a political economy viewpoint. Upland communities are typically very poor and may comprise ethnically distinct groups, so for distributional and political reasons governments may be reluctant to take steps that will hurt them economically without delivering tangible benefits elsewhere.

[20] A more subtle problem arises when the nature of the policy intervention is such as to isolate domestic prices from their world market equivalents. Temperate-climate vegetables in particular are highly income-elastic foodstuffs, and since the area suitable for their cultivation in tropical countries is limited to highlands, urbanisation and per capita income growth have driven up their domestic prices while the prices of competing crops, linked to the world market, have in many cases stagnated. The outcome is that the vegetable crops have come to be regarded as promising sources of future income – 'high-valued crops' deserving of public R&D support, while traditional highland agricultural products languish.

Temperate-climate vegetables – typical candidates for our Z sector goods – are consumed largely by relatively wealthy urbanites, so there is unlikely to be strong consumer demand for reduced protection.

On the environmental side, the inherent difficulty of using first-best measures to correct non-point pollution problems is compounded in uplands of developing countries by remoteness, poorly developed infrastructure and a low degree of participation by farmers in formal sector institutions such as the tax system.

In this setting, second-best solutions to the problems of resource misallocation and environmental degradation must be sought. In choosing τ by a shadow pricing rule rather than some market-based mechanism the social planner is using research resource allocation as a substitute for a Pigouvian tax on Z – or an equivalent subsidy on X.

If a shadow pricing rule is the appropriate criterion for R&D allocations, why do we observe divergences from this rule, as might be argued to be the case for potato? At the beginning of this article I suggested that part of the problem of inappropriate research resource allocation, where it occurs, could stem from a form of 'institutional failure'. Different agencies of government are charged with different tasks and these may conflict. The Ministry of Agriculture for example, may use farm profitability – at market prices – as a criterion for R&D resource allocation, whereas an environmental protection agency or power generation authority might take a broader view of agricultural development priorities.

In Southeast Asia there is considerable evidence of institutional failure of the kind that could inhibit effective policy formation for sustainable development of highland agriculture. In Thailand, for example, TDRI (1994) has documented the fragmentation of responsibilities among different (and often competing) government organisations:

> At present, agricultural research and extension work in the highlands are conducted on a piecemeal basis. Soil and water conservation research and technology are the responsibility of the Department of Land Development (DLD). Separate institutes of the Department of Agriculture carry out research on horticultural crops (fruits, flowers, vegetables) and field crops (rice, wheat, maize, soybean). Extending soil and water conservation technology and crop improvement methods to farmers are conducted independently . . . The present bureaucratic division within the Ministry of Agriculture does not lend itself to the solving of complex problems. (TDRI 1994, p. 133)

In this institutional setting specialised agencies focused on particular commodity groups are more likely to compete for a larger share of the research and extension budget than to collaborate on a socially optimal allocation. Moreover, specialised agencies are more vulnerable to 'capture' by well-organised producer groups seeking greater research budgets for their own commodities. Use of a commonly agreed set of shadow prices for project evaluation, including research planning, would be an important step in the direction of improved coordination of policy and programs across different agencies involved in agricultural development and natural resource management.

4. Conclusion

The factor market focus of most induced innovation theory, and its use of aggregate measures of output, have obscured some important relationships in diversified and distorted agricultural economies. First, small changes in relative factor endowments need not be reflected in factor price changes as long as the aggregate factor endowment vector remains within the economy's cone of diversification. Thus, small endowment changes may not send the signal that provides the main mechanism of induced innovation in the standard theory.

Second, in practice, much or even most agricultural R&D spending is directed at commodities, rather than at reducing the use of relatively expensive factors *per se*. Commodity biases in trade or price policy may alter the structure of agricultural production, and in so doing generate their own biases in the private demand for additional innovations.

Third, if the effective factor endowment is altered by agricultural growth – as when some crops deplete soils – or if agricultural growth generates externalities, then the market prices of factors will again provide misleading signals of relative factor scarcity. Agricultural R&D allocations based on these prices may redistribute income, but will not maximise social returns to scarce research resources.

In industrialised countries, the efficiency cost of biased demand for innovations is likely to be small, even as a fraction of agricultural income. In developing economies, where agriculture is much larger in terms both of factor allocation and of consumption expenditures, and where the total pool of resources for agricultural research is relatively small, the costs of misallocation could be large. In so far as the costs of soil erosion from upland areas of developing countries have been quantified, they appear to be surprisingly large in relation to national income (Barbier and Bishop 1995).

Empirically, the potato industry in the highlands of Southeast Asia is one for which the rate of return to research valued at shadow prices is likely to be far below that at market prices, and may well be negative once externalities are taken into account. Cultivation is privately profitable by virtue of import barriers and ancillary policies, including public and foreign aid expenditures on research, technology transfer, extension and marketing support. Under current technologies potato must be grown in high-altitude areas where soils are fragile, shallow and often steeply sloping; unresolved pest and disease problems are addressed by very intensive application of agricultural chemicals, with attendant water, air and soil pollution risks; and with poorly defined property rights, there is little prospect that upland farmers will internalise the full environmental costs of cultivation.

More research, both economic and agronomic, is required before there is a complete basis for research policy recommendations. The optimal rate of land degradation is never zero, so in some cases social returns to the production of high-valued crops in highlands may be positive even in spite of soil erosion and land degradation. On the agronomic front, little is known about the long-term environmental implications of intensive vegetable cultivation in tropical highlands. Applied research directed at finding more environmentally benign ways to produce such crops may well bear fruit. Failing this, however, and given the likelihood of institutional failure as described above, the risk is that high private profitability made possible by trade restrictions, market supports and externalities will successfully stimulate increased demand for productivity-enhancing research enabling the expansion of potato area without compensating reductions in the land-degrading properties of potato cultivation.

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