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# TECHNICAL CHANGE IN AGRICULTURE AND LAND DEGRADATION IN DEVELOPING COUNTRIES: A GENERAL EQUILIBRIUM ANALYSIS

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**Abstract**

Rapid land degradation in developing countries has generated a growing literature – both theoretical and applied – but the impact of this research boom on policy and on land use has so far been disappointing. Much of the literature suffers from major limitations, due to a strong "micro" focus and to the partial equilibrium nature of most analysis. This has inhibited the formulation of policies which can effectively change the behaviour of millions of farmers whose actions lead to soil degradation.

We present a general equilibrium framework that captures some key features of Asian developing country land use patterns, and that can be used to look at the impacts on land degradation of research and investment leading to technical progress of various kinds. Linkages between lowland and upland agriculture, and the potential for welfare-enhancing shifts from highly soil-erosive to less erosive crops with appropriate public policies are emphasized. Among our findings is the observation that some effects of the green revolution in lowland agriculture helped alleviate upland land degradation. These and other results highlight the importance of an integrated policy package to reduce the rate of upland land degradation in developing countries. Comparative statics results from the analytical framework are illustrated by simulations using a computable general equilibrium model.

## 1. Introduction

Rapid land degradation in developing countries, particularly that caused by soil erosion in sloping uplands, has been the source of much concern in recent years.[1] This concern has been reflected in substantial increases in socio-economic and agricultural research resources devoted to devising remedies. In the past, national and international agricultural research efforts focussed on raising productivity in relatively better-endowed lowlands. This was especially true in Asia, where agricultural productivity growth since the 1960s was mainly confined to well-irrigated lowlands where rice and wheat are grown.

Both political and economic factors influenced the concentration of research effort on lowlands. Those areas not only had the majority of the population (particularly those with greater political clout); they also offered the greatest potential for large and rapid productivity increases. Concerns about widening regional income disparities brought about by region-specific productivity changes have been reinforced by concerns about land degradation and "sustainable" development in general to bring about the shift in policy focus.

Despite these efforts, land degradation problems continue to worsen. Many reasons for failure of current strategies have been identified (see, for example Blaikie 1985), but

> perhaps the most important reason is the sheer difficulty of dealing with a myriad of relatively small-scale natural resource-using activities, which together are responsible for the bulk of environmental degradation. The traditional approach to environmental management is to invest in projects which have primarily environmental objectives ... This project-by-project approach is important and must be continued. Alone it is clearly inadequate, however, and needs to be supplemented by more comprehensive, wide ranging policies (Warford 1989:8; see also Repetto 1989:69).

If a major change in land use practices is needed to reverse the trend to undesirably high rates of land and forest degradation, policies must be designed which will have an impact on the millions of people engaged in agriculture; there is, therefore, a need for macroeconomic (economy-wide) analysis to support micro-economic analyses.

Our objective is to contribute to the development of economy-wide policies utilizing market mechanisms to promote upland resource use patterns that reduce the rate of land degradation. Our approach reflects the need to consider economy-wide linkages when developing and evaluating policies to arrest land degradation in the uplands.[2] Despite an extensive literature that has developed in this field in recent years there as yet is no rigorous analysis of how developments in other sectors of the economy influence and interact with changing agricultural practices in uplands. Given that governments have many policy goals such as economic growth, poverty alleviation, reduction of income inequality, and macroeconomic stability, an understanding of these economy wide effects is crucial to the formulation of *politically sustainable environmental policies*. Further, economy-wide interactions can significantly modify the effects of what are seen to be sector specific policies; in extreme cases ignoring such interactions may generate policy recommendations which, if implemented, would have the opposite of their intended effects.

In this paper we approach our task by means of a model which captures the stylized facts of a developing country economy in tropical Asia, though the key features of the model may be more broadly representative. We focus on the issue of soil erosion in uplands,[3] and abstract from many dimensions of the soil degradation problem in order to highlight some key economy-wide relationships. After introducing the model and exploring its properties in a series of comparative statics exercises, we conduct and report on several simulation experiments based primarily on data from the Philippines which illustrate some important points for policy making and analysis. A major part of our analysis deals with the issue of productivity improvements in agricultural crops due to technical progress and some implications for the allocation of research resources by national and international agricultural research bodies. We note, however, that the results of the technical change experiments are broadly similar to those that would be obtained had we instead simulated commodity price changes due, for example, to trade policy reform.

*Soil erosion and upland agriculture*

Upland soils are considered in the main to be non-renewable resources – at least over relevant human time horizons. Of course the fact that such soils are non-renewable does not imply that they should not be depleted - "mined" - at all: the relevant problem is that current depletion rates are above what is socially optimal. While much of the empirical evidence for this view is inadequate for conclusive proof, we assume here that present erosion rates are indeed "too high".

Many factors contribute to an explanation for land use practices resulting in sub-optimal rates of erosion: absence of full information regarding levels and consequences of soil erosion associated with particular practices; absence of well defined and enforced property rights; divergences between social and private time preference rates (Chisholm and Dumsday 1987), and on-site (intertemporal) and off-site (interregional) externalities. Analysis of the costs and benefits of reducing soil erosion is complicated by existing policy-induced price distortions. Moreover, the existence of externalities, whether due to off-site effects or to imperfect information about the future impact of current practices of soil productivity, means that removal of existing policy distortions may not be socially optimal. For the same reasons claims by proponents of agricultural price reforms (such as Repetto 1989) that ending underpricing of agricultural commodities would help reduce soil degradation are not necessarily correct.

Erosion rates vary greatly with crops and farming practices, even in similar ecosystems. The erosion rate associated with any given crop or crop mix depends to some degree on cultivation practices. Soil-conserving investments such as terracing can reduce erosion. For a given area of land, however, the dominant influence on the erosion rate is the type of crop grown. Tree crops, and tree crop-based cropping systems, are associated with much lower rates of soil loss through erosion than most annual food crop systems.[4] In the next section we develop a model in which at a given level of national income a reallocation of upland land from food crops to tree crops is considered to be welfare-improving, as the resulting land use pattern would generate lower soil erosion. Such a land use change is expected to occur in response to changes in relative profitability of crops.[5]

The model's key stylized facts mimic the structure of many developing country economies: an upland region produces tree crops (mainly for export) and food crops (mainly for domestic consumption) while most food is produced in lowland areas where (import competing) manufacturing industries are also located. At the core of our model is the link between relative food prices and land degradation: other things equal, a higher relative food price creates incentives to grow food (rather than tree crops) in the uplands, which increases erosion. For political reasons most developing country governments insulate domestic markets for staple foods from international price movements. In such circumstances the price of food is determined by supply and demand in domestic markets. This market structure means that productivity changes in food crops – a pertinent issue in the present context – tend to reduce food prices.[6]

## 2. Analytical model

In this section we present and analyse a model of a stylized developing country economy incorporating the features described above. The model aims to capture two key elements of the land degradation problem. These are the sector-specificity of some inputs and activities, and the inherently intersectoral nature of others. The model is heuristic: as set out here it is of the minimum dimensions consistent with the analysis we undertake.

In this model three goods are produced in two regions, upland and lowland. There are two sectors in the lowland, manufacturing industry and foodcrop agriculture. These two sectors each have a specific factor - capital in manufacturing and lowland land in agriculture. They compete for lowland labor, which is freely mobile between the lowland sectors. The structure of the lowland region is thus the familiar 2-good, 3-factor Ricardo-Viner economy (e.g. Jones 1971). The upland also has two sectors: one produces food, and the other tree crops. Production in each of these sectors uses upland labor and land endowments; both of these factors are freely mobile within the region. The upland economy thus corresponds to a standard 2x2 Heckscher-Ohlin economy (e.g. Jones 1965).

Our analysis links the two regions through national markets for food and labor. We assume for simplicity that food is homogenous, so consumer demand for this good makes no distinction between regions of origin. There is therefore only one price for food in both regions, based on an aggregate market clearing condition. The co-existence of two food production functions, however, enables us to explore issues of region-specific technical change in production of this important commodity.[7]

We use two alternative characterizations of the labor market. In the first, labor is region-specific as just described: in the short run, labor in each region is of sufficiently different quality that although it is mobile *within* a region, upland labor cannot replace lowland labor or vice versa. A dual labor market implies two independent wage rates, one each for lowland and upland labor. In the second case, we assume labor to be homogeneous and mobile among all sectors. The upland economy becomes Heckscher-Ohlin with variable labor supply. In this case there is only one economy-wide wage for labor. The simulation experiments discussed in section 3 employ each of these labor market characterizations.[8]

Lastly, we assume manufactures and tree crops to be tradable goods, the latter exported and the former competing with imports. Because developing economies are typically small in relation to world markets for their traded goods we regard prices for these commodities as exogenous. By contrast, food is assumed to be non-traded; hence its price is endogenous.

Production and Factor Demand

We characterize producers in each sector as minimizing short-run production costs subject to constant returns to scale technology. Production and factor demand in each sector is represented by an indirect unit cost function $C$ in output $Y$, a vector of factor prices $W$, and technology $A$. Minimization of $C(W,Y,A)$ with respect to factor prices yields mobile input demand functions $X(W,Y,A)$ and, in the lowland sectors with specific factor endowments $Z_j^*$, output supply functions $Y(W, Z, A)$. (Henceforth we denote exogenous quantities by superscript asterisks). Let the manufacturing, lowland food, upland food, and tree crop sectors be identified by subscripts 1 to 4 respectively. We write lowland and upland factor demand relations as:

$$X_{lj} = X_l(W_{ll}, Y_j, A_{lj}^*) \qquad j = 1,2 \qquad (1.1)$$

$$X_{ij} = X_{ij}(W_{u}, Y_j, A_{ij}^*) \qquad i = lu, nu; j = 3,4 \qquad (1.2)$$

where $X_{lj}$ is labor demand in lowland sector $j$ with price $W_{ll}$, $W_u$ is a vector of upland factor prices; and subscripts $lu$ and $nu$ indicate upland labor and land respectively. $A_{ij}^*$ is the (positive) rate at which, at constant prices, technical progress reduces the quantity of $X_{ij}$ required per unit of output produced. Cost minimization also implies lowland supply relations:

$$Y_j = Y_j(W_{ll}, Z_j^*, A_j^*), \qquad j = 1,2 \tag{2}$$

where $Z_j^*$ is the endowment of the sector-specific factor, and $A_j^*$ is the overall rate of technical change. Payments to all factors equal gross returns in each sector, which determines returns to sector-specific factors in the lowlands (eq. (3.1)), and output in upland sectors (eq. (3.2)):

$$P_jY_j = (W_{ll}X_{lj} + W_{zj}X_{zj})/A_j^* \qquad j = 1,2 \tag{3.1}$$

$$P_jY_j = (W_{lu}X_{lj} + W_{nu}X_{nj})/A_j^*. \qquad j = 3,4 \tag{3.2}$$

Note from these equations that technical progress is cost-reducing. At constant prices an increase in $A_j^*$ reduces factor requirements per unit of output in sector $j$.[9]

Factor Markets and Factor Prices

Under the dual labor market assumption, upland and lowland labor as well as upland land are intersectorally mobile only within a single region. Their prices are determined by regional full employment conditions:

$$X_{l1}+X_{l2} = X_{ll}^* \tag{4.1}$$

$$X_{i3}+X_{i4} = X_{iu}^* \qquad i = lu, nu \tag{4.2}$$

where $X_i^*$ denotes the (exogenous) endowment of factor $i$. The alternative assumption of a single labor market is represented by including condition (5), in which labor demand in *all* sectors is equal to the aggregate labor endowment:

$$\sum_{j=1}^{4} X_{lj} = X_{ll}^* + X_{lu}^*. \tag{5}$$

If the equality in (5) holds then it follows from (4.1) and (4.2) that $W_{lu} = W_{ll}$, and rising labor productivity in one region induces outmigration from the other. Otherwise the two labor markets are not directly linked and wages may move independently in each region.

Food market and trade

The model distinguishes between traded goods (treecrops and manufactures) and non-traded goods and factors (food and factors of production).[10] We assume that basic prices of traded goods are determined by world prices and the exchange rate of domestic for foreign currency. By contrast, food's price is determined wholly by domestic demand ($C_f$) and aggregate supply ($Y_f$), as defined in (6) - (8):

$$Y_f = C_f \tag{6}$$

$$C_f = C_f(P, Y) \tag{7}$$

$$Y_f = Y_2 + Y_3 \tag{8}$$

In (7), food demand is a function of the vector of commodity prices $P$ (since both regions produce homogeneous food there is only one food price $P_f = P_2 = P_3$) and income $Y$, defined equivalently as the value of domestic production or of payments to factors:

$$Y \equiv Y_f P_f + Y_t P_t + Y_m P_m \equiv \sum_i \sum_j X_{ij} W_i + \sum_k Z_k W_{zk}. \quad (i=lu,\ nu,\ ll;\ j=1,\ldots,4;\ k=1,2) \tag{9}$$

We define the *real exchange rate* to be the ratio of food's price to an index of traded goods' prices. Changes in this ratio resulting directly and indirectly from exogenous changes in technology, endowments, or the world prices of traded goods are central in determining alterations in the sectoral structure of production and associated resource allocations (Corden and Neary 1982). The role of the real exchange rate in determining resource allocation is readily seen in the upland, where one traded and one non-traded good are produced. A real appreciation – a rise in the relative price of food – directly induces resource reallocation from treecrops to upland food production. In addition to this direct impact, the real exchange rate is also a conduit by which supply changes in lowland sectors influence allocation of upland land and labor resources.

We assume a zero balance of merchandise trade, which implies that the value of imports always equals that of exports:

$$P_I Y_I{}^I + P_4 Y_4 = 0, \tag{10}$$

where $Y_1{}^t$ is the quantity imported of the manufactured good. The balanced trade assumption requires that any change in the volume of either good traded be compensated by an adjustment in trade of the other. For example, an increase in the value of manufactured imports brought about by a reduction in domestic production must be financed (at constant world prices) by an increase in tree crop exports. As long as consumers operate on their budget constraints and all other markets in the economy clear, Walras' law ensures that (10) will be satisfied and it need not be explicitly included in calculations.

In the short run factor endowments, technical change and international prices of tradable goods are exogenous. Equations (1) to (9) therefore form a system of 20 relations solving 20 endogenous variables: commodity supplies, factor demands and prices, aggregate supply, demand and price of food, and aggregate income.

The model in proportional changes.

We are interested in the comparative static effects of changes in technology, prices and factor endowments. These can be approximated by expressing the model in terms of proportional changes of variables, then solving for changes in endogenous prices and quantities resulting from 'shocks' to exogenous variables. For all variables $X$ let a lower case $x \equiv dX/X$ be the proportional change in $X$. The complete model of (1)-(9) can then be written as (11)-(19) in Table 1. These equations describe responses of factor demands, sectoral outputs, food demand, prices and income to exogenous changes in endowments, technology and tradables' prices. Parameters of the structural model are also defined in Table 1.

Our focus rests on any change in the allocation of upland land between food and tree crops which might occur in response to a change in one or more exogenous variables. For a given endowment of upland land, an increase in tree crop land is the same as a reduction in upland food land, so we will consider only the latter. Equation (11), with $i = nu$ and $j = 3$, describes the change demand for land in upland food in terms of changes in upland food output, factor prices and technology. However, output and factor prices may themselves be altered by exogenous changes; moreover, (11) does not by itself indicate the response of upland food land area to economic changes in other sectors. We obtain the general equilibrium change in upland land demand by deriving reduced form equations that show the influence of exogenous changes in technology, prices and factor endowments on regional food output, factor prices and the real exchange rate.[11]

*The lowland economy*

In the lowland economy there are five unknown variables besides product prices: returns to sector-specific factors, lowland wages, and sectoral outputs. We seek expressions for the market-clearing changes in these variables. Since returns to specific factors are determined as residuals in equations (15), we solve those equations for the $w_{zj}$ in terms of commodity prices and lowland wages:

$$w_{zj} = \frac{1}{\theta_{zj}}(p_j + a_j^* - \theta_{lj}\, w_{ll}) \qquad j = 1,2 \qquad (20)$$

Using (20), we derive the market-clearing condition for lowland wages by summing (13) over $j$ and substituting into the factor market clearing condition (6):

$$w_{ll} = \varepsilon_{l1}(p_1 + a_1^*) + \varepsilon_{l2}(p_2 + a_2^*) + \varepsilon_{ll}\left(\sum_{j=1}^{2}\lambda_{lj}(z_j^* + a_{zj}^* - a_{lj}^*) - x_{ll}^*\right) \quad j = 1,2 \qquad (21)$$

where $\varepsilon_{lj} = \dfrac{\lambda_{lj}\sigma_j\theta_{zk}}{\lambda_{l1}\sigma_1\theta_{z2} + \lambda_{l2}\sigma_2\theta_{z1}} > 0$ for $j,k = 1,2;\ j \neq k$, and $\varepsilon_{ll} = \dfrac{\theta_{z1}\theta_{z2}}{\lambda_{l1}\sigma_1\theta_{z2} + \lambda_{l2}\sigma_2\theta_{z1}} > 0$.

The $\varepsilon_{lj}$ terms are elasticities of lowland wage response to changes in product prices and Hicks-neutral technical progress (when technical progress is neutral with respect to factors, other technical change terms cancel because $a_{zj}^* = a_{lj}^*$). We use (20) and (21) in (14) to write changes in lowland outputs in terms of exogenous variables and the price of food:

$$y_j = \varepsilon_j(p_2 + a_2^* - p_1 - a_1^*) + (z_j + a_{zj}^*) - \varepsilon_{jj}\varepsilon_{ll}\left(\sum_{j=1}^{2}\lambda_{lj}(z_j^* + a_{zj}^* - a_{lj}^*) - x_{ll}^*\right), \quad j = 1,2 \qquad (22)$$

where $\varepsilon_j$ and $\varepsilon_{jj}$ are defined as $\varepsilon_1 = -\varepsilon_{11}\varepsilon_{l2} < 0$ and $\varepsilon_2 = \varepsilon_{22}\varepsilon_{l1} > 0$; and $\varepsilon_{jj} = \dfrac{\sigma_j\theta_{lj}}{\theta_{zj}} > 0$.

Together, (21) and (22) describe changes in wages and output within the lowland region in terms of the price of food, exogenous output prices, factor endowments and technical progress. In (22) output from a sector is increased by technical progress, a price rise, growth in its specific factor endowment or labor force growth. Output is diminished by technical progress, a price rise, or specific factor growth in the other sector.

*The upland economy*

The expression $(w_i - w_k)$ in (11) is the proportional change equivalent of the upland factor price ratio $W_i/W_k$. Subtracting (12) with $j$=4 from (12) with $j$=3 yields:

$$\theta(w_l - w_n) = (p_3 - p_4) + (a_3^* - a_4^*), \tag{23}$$

where $\theta = \theta_{l3} - \theta_{l4} > 0$ if sector 3 is labor-intensive relative to sector 4 (Jones 1965). Without technical progress, changes in upland factor prices are determined entirely by changes in relative commodity prices. At constant commodity prices, Hicks-neutral technical change alters relative factor prices in exactly the same way as for the corresponding commodity price change.

Changes in upland commodity supplies are found by substituting (11) into the factor market clearing conditions (16). Rearranging, and substituting the definition of $(w_l - w_n)$ from (23), we obtain expressions relating changes in upland output to changes in commodity prices, factor endowments and technical progress:

$$y_3 = \varepsilon_3(p_3 - p_4 + a_3^* - a_4^* + T_3) \tag{24}$$

$$y_4 = -\varepsilon_4(p_3 - p_4 + a_3^* - a_4^* - T_4) \tag{25}$$

where:

$$\varepsilon_j = (\theta\lambda)^{-1}\left(\lambda_{lk}(\lambda_{nj}\sigma_j\theta_{lj}+\lambda_{nk}\sigma_k\theta_{lk}) + \lambda_{nk}(\lambda_{lj}\sigma_j\theta_{nj}+\lambda_{lk}\sigma_k\theta_{nk})\right) > 0; \quad (j,k\in(3,4);\ j \neq k);$$

$$T_j = \theta\left(\lambda_{nj}\left(\sum_j \lambda_{lj}a_{lj}^* + x_{lu}^*\right) - \lambda_{lj}\left(\sum_j \lambda_{nj}a_{nj}^* + x_{nu}^*\right)\right);$$

$$\theta = (\theta_{l3} - \theta_{l4}); \qquad \lambda = (\lambda_{l3} - \lambda_{n3}); \qquad \theta\lambda > 0.$$

At constant commodity prices, Hicks-neutral technical progress in sector 3 (a positive change in $a_3^*$) increases that sector's output and reduces output in sector 4, and vice versa. The magnitude of output response to a price change or to Hicks-neutral technical change depends on the values of sectoral supply elasticities, $\varepsilon_j$. These in turn depend for their magnitude on relative sector size and factor intensity and on the elasticities of factor substitution. If sector 3 is relatively labor (land) intensive then $\theta$ is positive (negative), and growth in the endowment of labor (land) will raise (lower) output in the sector. Similarly, factor-specific technical progress (equivalent to growth in the effective endowment of that factor) increases or reduces sectoral outputs depending on relative factor intensity. Both results are illustrations of the Rybczinski theorem. Since our analysis will not deal with non-neutral technical progress or upland factor endowment growth, we have collected those terms as $T_j$.

Substituting from (23) and (24) into (11) and collecting terms, we obtain an expression for the change in demand for land in upland food production in terms of commodity prices, upland factor endowments and rates of technical change:

$$x_{n3} = \varepsilon_{n3}\left(p_3 - p_4 + a_3^* - a_4^* + T_3\right) - a_{n3}^* , \qquad (26)$$

where $\varepsilon_{n3} = (\varepsilon_3 + (\sigma_3\theta_{l3}/\theta)) > 0$ is the elasticity of land demand in upland food with respect to output prices. Equivalent expressions may be obtained for other upland factor demands. The first term on the right hand side of (26) describes the response of upland food land demand to upland price changes and Hicks-neutral technical progress. The second term captures effects of growth in upland factor endowments and factor-specific technical progress, as for (24) and (25).

The only unknown change on the right hand side of (26) is that in the price of food. Because this price is endogenous, signs of factor demand responses to technical progress or to rises in other commodity prices depend in part on how the price of food responds to the same exogenous change. Suppose, for example, that neutral technical change in the treecrop sector alters $P_3$ endogenously. Then

$$sgn\left\{\frac{x_{n3}}{a_4^*}\right\} = sgn\left\{\frac{p_3}{a_4^*} - 1\right\} \gtrless 0.$$

For given relative factor intensity the sign and the magnitude of a change in the real exchange rate determines whether demand for land in sector 3 is increased or diminished by technical progress. That relative price change is determined in the interregional market for food.

*The food market.*

Food price changes depend on aggregate supply and domestic demand. The former is in turn susceptible to influences from non-food sectors in both regions, transmitted through changes in markets for intersectorally mobile factors. In the absence of interregional factor flows (i.e. in the dual labor market case) the food pricing condition is thus the intersectoral conduit for changes in upland land allocation.

Aggregate food supply is obtained by substituting the regional food supply functions from (22) and (24) into (18). Since the price of food is the same in both regions we define the food price change $p_f = p_2 = p_3$ and collect terms to obtain:

$$y_f = (\delta_2\varepsilon_2 + \delta_3\varepsilon_3)p_f - \delta_2\left(\varepsilon_2(p_1 + a_1^*) - (z_2 + a_{z2}^*) + \varepsilon_{22}\varepsilon_{ll}\left(\sum_{j=1}^{2}\lambda_{lj}(z_j^* + a_{zj}^* - a_{lj}^*) - x_{ll}^*\right)\right)$$
$$- \delta_3\varepsilon_3\left(p_4 + a_4^* - a_3^* - T_3\right) \tag{27}$$

where $\delta_2 = \frac{Y_2}{(Y_2+Y_3)}$ and $\delta_3 = \frac{Y_3}{(Y_2+Y_3)}$ are regional shares in food production. Aggregate food supply response is homogeneous of degree zero in prices. Its own-price supply elasticity is a $\delta$-weighted average of upland and lowland elasticities. Supply responds positively to own price rises and to technical progress in food sectors, and negatively to price rises and technical progress in non-food sectors.

Changes in food demand depend on price changes and growth in aggregate income. For a given exogenous change the latter has two components: income growth at constant prices (due, for example, to technical change or increased factor endowments) and the effects of consequent adjustments in the market for food. Derivation of the compensated food demand equation (28) exploits this decomposition and applies the Slutsky relationship (full details are provided in an appendix) to yield, for a representative technical change in the $j$'th sector:

$$c_f = \eta(\gamma_j\tau_j a_j^* - p_f) \tag{28}$$

where $\eta$ is the compensated food demand elasticity, $\gamma_j$ is the share of national income earned in sector $j$, and $\tau_j$ is the elasticity of sector $j$'s output with respect to the technical change – that is, the partial equilibrium supply elasticity. (Equivalent expressions can be derived for changes in other exogenous variables, for instance factor endowments). The general equilibrium change in food's price due to the change in $A_j^*$ is derived by equating changes in food supply (27) and demand (28), and solving for $p_f$. For the example of technical change we obtain:

$$p_f = \frac{(\eta\gamma_j\tau_j + E_j)}{D} a_j^*, \tag{29}$$

where $D = (\delta_2\varepsilon_2 + \delta_3\varepsilon_3 + \eta) > 0$ , and $E_j$ stands for the coefficient of $a_j^*$ in (27). $D$ is the familiar difference between the price elasticities of food supply and demand, and is positive as long as food is a "normal" good. The sign of $p_f$ therefore depends on the sign of the numerator of (29). In this, the first term $\eta\gamma_j\tau_j$ is positive. The second term measures the amount by which a given change increases or reduces the aggregate supply of food, and may be positive or negative depending on which exogenous variable or variables are changing.The coefficients of some exogenous variables in (27) are unambiguously positive or negative; others' signs depend on relative factor intensity of upland sectors.

Some comparative statics

Once the change in $P_f$ has been established from (29) we can sign changes in sectoral outputs and the prices of mobile and specific factors, and thereby establish the direction of factor flows between sectors in the upland region. This analysis is facilitated by observing two separate mechanisms at work. The first (the *resource movement effect*) is the effect of factor and product market adjustments at a constant level of demand for the non-traded good (i.e. when $\eta$=0). The second - the *spending effect* - captures *only* effects of a change on the demand for food induced by a change in income. By itself, the spending effect always raises demand for food and therefore demand for land used in upland food, so the sign and relative magnitude of the resource movement effect determines whether the change in upland food land demand is positive or negative. Table 2 summarizes the effects of selected exogenous shocks on the demand for land in upland food, showing total effects ($\eta$>0) as well as spending effects ($\eta$=0). For brevity, in this table we continue to maintain the dual labor market assumption; moreover, we assume that upland food is labor-intensive relative to tree crops, so $\theta > 0$.

The four cases analyzed are those of technical progress in lowland food, upland food, and tree crops, and an increase in the endowment of manufacturing capital. In the absence of a spending effect, two changes reported in table 2 reduce upland food area (technical progress in tree crops and in lowland food), and two increase it (technical progress in upland food and an increase in manufacturing capital). The analysis is similar for all cases: without an income effect, constant-price demand for food is unaffected by any exogenous change. If a change causes food supply to increase or decline in one region, food production in the other must reduce or increase to clear the market. In this way adjustments in the food market transmit effects of exogenous shocks between sectors.

*Technical progress in tree crops* increases profitability in tree crops relative to food crops in uplands. Land and labor are drawn from the latter sector to the former, and food production switches from upland to lowland. With no income effects ($\eta=0$) Table 2 shows that the extent of a reduction in upland food area depends on the capacity of the *lowland* region to expand supply to meet existing food demand. If lowland food supply is inelastic with respect to price (i.e. if $\varepsilon_2$ is small) – or if the lowland supply response is insignificant because the sector contributes little to aggregate food production ($\delta_2 \rightarrow 0$) – then the reduction in upland food area will be correspondingly small, and vice versa.

*Technical progress in lowland food* increases supply from that sector at constant prices. With no change in food demand this reduces the profitability of food production in upland, and land in that region is switched to tree crop production. With a dual labor market the interregional impact of technical change in lowland food alters upland resource allocation only through a reduction in the price of food. Upland food production declines because the price of food has fallen.[12,13]

*Spending effects.*

The outcomes of the above two forms of technical progress at constant food demand are "desirable" from a soil conservation viewpoint. Technical progress generates new income, however, part of which is spent on food and the remainder on manufactures. By itself, this "spending effect" increases the price of food and therefore tends to cause the area of land devoted to food to expand. Table 2 shows that for some forms of technical change a large spending effect could diminish or even reverse a reduction in upland food land area. The size of the spending effect on food demand is governed by the size (measured by GNP share) of the expanding sector, so the possibility that spending effects will dominate resource movement effects in the demand for upland food land is greater, the larger is the expanding sector, the greater is the technical change response ($\tau$), the smaller is the lowland food sector ($\delta_2$), and the less elastic is its supply response ($\varepsilon_2$). We cannot rule out apparent paradoxes, for instance that technical progress in tree crops will *increase*, rather than decrease, the upland food crop area.

The other two shocks analyzed in Table 2 unambiguously cause food area in uplands to increase; resource movement and spending effects reinforce one another. *Technical progress in upland food* increases the relative profitability of producing food rather than tree crops in uplands, so land and labor switch to the former from the latter. At constant food demand this form of technical progress causes the price of food to decline, but the losers on this "technological treadmill" are farmers in lowlands, where technical change has not reduced unit costs. Food production therefore increases in uplands and declines in lowlands.

Less intuitively, *expansion of manufacturing capital* also increases the relative profitability of food in uplands. Because the lowland sectors compete for labor, capital growth in manufacturing attracts labor from lowland food, causing its output to decline. At constant food demand ($\eta$=0) the burden of meeting demand shifts to the upland. Table 2 shows that the increase in upland land demand is larger, the larger is manufacturing's share of the lowland labor force ($\lambda_{Y1}$), and therefore the greater the shrinkage of lowland food when manufacturing expands. Equivalently, we may refer to the trade balance condition, observing that an increase in expands. Equivalently, we may refer to the trade balance condition, observing that an increase in domestic manufacturing output implies lower demand for foreign currency and therefore less exports, which in turn means reduced tree crop sector demand for land and labor.

The spending effect[14] is moderated by the size of the tree crop sector and the income elasticity of food demand. Returns to manufacturing capital decline. Returns to lowland land may rise or fall; a fall is more likely, the larger is the rise in lowland wages.

Comparative statics predictions such as these help identify technical and market parameters that are likely to be important in determining the outcome of a technical change or other shock. However, comparative static results can typically be definitively signed only in models of minimal dimensions. Even in the simple model just presented we could predict signs of changes under the assumption of a unified labor market only by imposing restrictions on the values of many parameters. When changes in endogenous variables cannot be predicted *a priori*, numerical simulation provides an appropriate alternative.

### 3. Some illustrative experiments

In this section we investigate the effects of the above technical progress and endowment changes in a computable model using a parameter set broadly representative of the structure of the Philippine economy[15]. These data (Table 3) indicate that of the four sectors represented manufacturing is the least labor intensive, while in uplands, tree crops are more land intensive than upland food. We assume sectoral Allen elasticities of substitution of 0.5. Food demand is assumed relatively price and income-inelastic, with elasticity values of -0.4. and 0.4 respectively.

Tables 4 and 5 show results of four experiments conducted using the model of Table 1. Table 4 gives results for a dual labor market; Table 5 assumes unified markets for both food and labor. The tables report percentage changes of endogenous variables in response to 1% Hicks-neutral technical progress shocks in upland and lowland food and tree crops, and a 1% increase in manufacturing sector capital. The figures in the tables are therefore elasticities of endogenous variable responses to exogenous changes. Because the model is linear in proportionate changes of variables, the effect of an $n\%$ change in an exogenous variable can be calculated as $n$ times the 1% shock shown in the tables. For example, the elasticity of land allocation to upland food with respect to technical progress in lowland food is shown in Table 5 as –1.85. A five per cent rate of technical progress in lowland food would therefore produce a 9% decline in upland food area.

3.1: Technical change in lowland food production.

The first columns of Tables 4 and 5 report results of Hicks-neutral technical progress in the lowland food sector (alternatively, these could be interpreted as the effects of an output price rise). This is a very important empirical case. For three decades national and international research expenditures have been devoted almost exclusively to achieving higher productivity in "favourable" agricultural areas, well-irrigated or with adequate and dependable rainfall, located mainly in lowlands. Productivity changes associated with the green revolution in rice and wheat were confined mainly to lowlands. What impact might they have had on upland land allocation?

Our experiments show that under both labor market assumptions, technical progress in lowland agriculture raises its output and increases lowland land values. Upland food production declines and tree crop production expands. Assuming erosion from cultivation of tree crops to be lower than for food, we conclude that other things being equal, the green revolution reduced the rate of upland land degradation. In the dual labor market case (Table 4) our simulations confirm the Stolper-Samuelson prediction that returns to upland labor (used relatively intensively by the food sector) decline, and returns to upland land rise. When labor is regionally mobile expansion of labor-intensive lowland food overturns this result, with technical progress causing wages to rise while returns to upland land decline.

3.2: Technical Change in Tree Crops

The second columns of Tables 4 and 5 report simulation results for Hicks-neutral technical progress in tree crops. Technical progress in export-oriented tree crop sectors has been substantial in the past, and is increasingly targeted as a means of addressing upland land degradation problems in developing countries. Our results indicate that technical change in tree crops raises that sector's output and the value of upland land. Upland food area declines slightly; the elasticity of upland food land demand with respect to technical progress in tree crops is –0.39. This result, however, is highly sensitive to the values of certain key parameters - primarily the income elasticity of demand for food, which determines the magnitude of the spending effect. The elasticity of the change in upland food land area with respect to a change in the value of $\eta$ is 0.3.[16] A 10% increase in the value of $\eta$ (i.e. from 0.4 to 0.44) reduces the change in upland food area from -0.39 to -0.25, and the higher the value of the food demand elasticity, the less likely is a decline in upland food area. Any value of the income elasticity of food demand greater than 0.5 leads to the paradox alluded to in section 2: the proportion of upland land devoted to tree crops actually declines when there is technical progress in tree crops. This outcome illustrates the importance of the role of the income elasticity of demand for food. Higher productivity in tree crops increases national income; part of the increase is spent on food, bidding up its price and thus inducing a supply response. If the income effect on food demand is sufficiently large, it may become profitable for farmers in uplands to withdraw land from tree crops and allocate it to food. Thus technical progress in production of tree crops will not *necessarily* reduce upland food cultivation; indeed upland food crop area may even expand.

3.3: Increase in manufacturing capital.

An increase in the endowment of manufacturing capital is roughly equivalent to an exogenous investment boom in that sector. In the dual labor market case capital growth raises output and employment in manufacturing. Wages rise, pushing up costs in lowland food, and that sector's output shrinks accordingly. Even though there are no factor flows between upland and lowland, and even in the absence of spending effects, the manufacturing 'boom' raises the fraction of upland land used to grow food. Manufacturing expansion made possible by capital growth bids up lowland wages, raising costs and reducing supply in lowland food production, and thus causing a real appreciation – a rise in the relative price of food. Because food demand is relatively price-inelastic, reduced lowland supply induces a positive response among upland food producers. They expand food production at the expense of treecrops, which compete with upland food for land and labor.

As the simulations show, a significant consequence of the manufacturing sector's expansion is an increase in upland land under food crops, while the value of upland falls. Treecrop production is land-intensive relative to upland food production. Consequently, while shrinkage of the treecrop sector releases land and upland labor in the proportions in which they are employed in that sector, they are taken up by the upland food sector in proportions reflecting that sector's relative labor-intensity. The result is that the unit value of upland land declines. If sustained, such a decline would reduce returns to investment in land-preserving technologies and techniques by upland farmers, whatever crop they produce.[17]

*Factor prices and income distribution .*

One of the principal proximate causes of upland land degradation is poverty, which is associated with high private rates of time discount in the use of natural resources (Perrings 1989) as well as with inability or unwillingness on the part of poor families to endure unemployment or underemployment in lowlands or urban areas, thus increasing the attraction of migrating to the upland agricultural "frontier". In addition to assessing changes in upland land use, there is considerable policy relevance in asking to whom the gains from technical progress accrue. If a technical change reduces upland food area at the expense of lower real wages, for example, its environmental benefits (in terms of reduced upland food area) are likely in the long run to be eroded by more rapid migration from lowland to upland. In our simulations technical change in lowland food and in tree crops raise wages and reduce upland food land area, although the impact of the tree crop change is the smaller of the two. By contrast, technical change in upland food not only increases the area devoted to that crop; it also reduces wages (in terms of tradables' prices) by causing the labor-intensive lowland food sector to contract.

## 4. Conclusions

We have presented a small general equilibrium model which illustrates interactions between upland and lowland agricultural systems and which highlights implications of productivity or output price changes in different sectors for upland soil erosion rates, implied by shifts of land between more erosive food crops and less erosive tree crops.

Productivity changes in lowland food agriculture could substantially reduce the rate of land degradation in uplands by altering the relative profitability of food and tree crops in favor of the latter. Our results suggest that the shift to tree crops in uplands will be stronger if labor is indeed mobile among regions. A drawback of a strategy which relies solely on technical progress in lowland food is that it could lead to greater regional income disparities, as owners of upland land (typically among the poorest groups in a developing country) tend to see returns to their land assets decline. Simultaneous technical progress in both tree crops and lowland food is most likely to achieve the desired shift in land allocation while alleviating income losses suffered by upland landowners.

These results are illustrative only and depend on parameter values, including factor intensity rankings and demand elasticities. In addition, we have abstracted from the influence of changing land values on potential adoption of land-conserving technologies and infrastructural investments. Nor do we attempt to quantify the costs of erosion, whether on-site or off-site. These relationships are as yet poorly understood; parameters governing the rate of lowland land degradation due to upland soil erosion have not been empirically established. However, our results show that technical changes in lowland food and in tree crops unambiguously increase welfare at present parameter values, because they both increase GNP *and* reduce erosion. Welfare consequences of the other two cases (upland technical progress and growth of manufacturing capital) are ambiguous, since these changes raise GNP but also increase erosion. In the latter cases, empirical analysis is required to established the direction of welfare change. However, in both cases in which the results are ambiguous on welfare, inclusion of a damage function capturing off-site costs of upland food production would serve only to strengthen our conclusions.

Our results highlight the need to recognise links between productivity changes in lowlands and those in uplands when addressing issues of upland land degradation. Product and input markets bridge geographical barriers. Research strategies and decisions on research resource allocation should take account of these market links, which make it impossible to separate economic-environmental problems of different regions. In some circumstances a wholesale shift of research resources to the uplands (and particularly to upland food crop sectors) might not only be sub-optimal but could even be counter-productive in terms of its impact on soil erosion. Similarly, in certain circumstances tradable sector price reforms may aggravate the soil erosion problem.[18]

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**Table 1: The model in proportional changes**

Upland sectors ($j = lu,nu; j = 3,4$):

(11) $$x_{ij} = y_j - \theta_{kj}\,\sigma_j(w_i - w_k) - a^*_{ij}$$

(12) $$p_j = \sum_i \theta_{ij} w_i - a^*_j$$

Lowland sectors ($j = 1,2$):

(13) $$x_{lj} = y_j - \theta_{zj}\,\sigma_j(w_l - w_{zj}) - a^*_{lj}$$

(14) $$y_j = z^*_j - \theta_{lj}\,\sigma_j(w_l - w_{zj}) + a^*_{zj}$$

(15) $$p_j = \theta_{lj} w_l + \theta_{zj} w_{zj} - a^*_j$$

Mobile factor market ($i = ll,lu,nu$):

(16) $$\sum_j \lambda_{ij} x_{ij} = x^*_i$$

Food market:

(17) $$c_f = \eta(y - p_f)$$

(18) $$c_f = \sum_j \delta_j y_j$$

(19) $$y = \sum_j \gamma_j(y_j + p_j)$$

Parameters:

$\theta_{ij}$ = Share of factor $i$ in total production cost of sector $j$.

$\sigma_j$ = Allen elasticity of substitution in sector $j$.

$\lambda_{ij}$ = Fraction of endowment of factor i employed in sector $j$.

$\eta$ = compensated income elasticity of food demand

$\gamma_j$ = GNP share of sector $j$.

$\delta_j$ = Share of sector $j$ in total food production ($j = 2,3$)

**Table 2: Upland land demand effects of exogenous changes.**

| Type of change | Exog. variable | Expression[a] | Sign when $\eta = 0$ | Sign when $\eta > 0$ |
|---|---|---|---|---|
| Tech. progress in lowland food | $a_2^*$ | $\frac{x_{n3}}{a_2^*} = \varepsilon_{n3}\left(\frac{p_3}{a_2^*}\right) = \frac{\varepsilon_{n3}}{D}\left(\eta\gamma_2\tau_2 - \delta_2\varepsilon_2\right)$ | $< 0$ | $\gtrless 0$ |
| Tech. progress in upland food | $a_3^*$ | $\frac{x_{n3}}{a_3^*} = \varepsilon_{n3}\left(\frac{p_3}{a_3^*} + 1\right) = \frac{\varepsilon_{n3}}{D}\left(\eta(1+\gamma_3)\tau_3 + \delta_2\varepsilon_2\right)$ | $> 0$ | $> 0$ |
| Tech. progress in upland tree crops | $a_4^*$ | $\frac{x_{n3}}{a_4^*} = \varepsilon_{n3}\left(\frac{p_3}{a_4^*} - 1\right) = \frac{\varepsilon_{n3}}{D}\left(\eta(\gamma_4\tau_4 - 1) - \delta_2\varepsilon_2\right)$ | $< 0$ | $\gtrless 0$ |
| Increase in mfg specific factor | $z_1^*$ | $\frac{x_{n3}}{z_1^*} = \varepsilon_{n3}\left(\frac{p_3}{z_1^*}\right) = \frac{\varepsilon_{n3}}{D}\left(\eta\omega_{z1} + \lambda_{l1}\delta_2\varepsilon_2\right)$ | $> 0$ | $> 0$ |

[a] Obtained from (26), using (29).

**Table 3: Data base for simulation experiments**

| | Sector: | | | |
|---|---|---|---|---|
| | Manuf. | Lowland food | Upland food | Tree crops |
| 1. Sector shares in factor demand ($\lambda_{ij}$) | | | | |
| Upland land | 0 | 0 | 0.38 | 0.62 |
| Upland labor | 0 | 0 | 0.50 | 0.50 |
| Lowland labor | 0.33 | 0.67 | 0 | 0 |
| Lowland land | 0 | 1.00 | 0 | 0 |
| Mfg. capital | 1.00 | 0 | 0 | 0 |
| 2. Factor shares in total cost ($\theta_{ij}$) | | | | |
| Upland land | 0 | 0 | 0.50 | 0.62 |
| Upland labor | 0 | 0 | 0.50 | 0.38 |
| Lowland labor | 0.33 | 0.40 | 0 | 0 |
| Lowland land | 0 | 0.60 | 0 | 0 |
| Mfg. capital | 0.67 | 0 | 0 | 0 |
| 3. Sector shares in GNP ($\gamma_j$) | | | | |
| | 0.30 | 0.35 | 0.15 | 0.20 |
| 4. Allen elasticities of factor substitution ($\sigma_j$) | | | | |
| | 0.50 | 0.50 | 0.50 | 0.50 |

**Table 4: Effects of 1% changes in some exogenous variables under assumption of dual labor markets.**

| Endogenous Variable | Tech. progress in lowland food | Tech. progress in treecrops | Incr. in manf. specific factor | Tech. progress in upland food |
|---|---|---|---|---|
| Output | Percentage changes | | | |
| Upland food | −1.58 | −0.38 | 0.59 | 1.31 |
| Lowland food | 1.10 | 0.10 | −0.14 | −0.10 |
| Treecrops | 1.22 | 1.82 | −0.45 | −0.24 |
| Manufacturing | −0.16 | −0.17 | 0.89 | 0.17 |
| Labor Demand | | | | |
| Upland food | −1.42 | −0.95 | 0.53 | 0.28 |
| Lowland food | 0.24 | 0.25 | −0.34 | −0.25 |
| Treecrops | 1.42 | 0.34 | −0.53 | −0.28 |
| Manufacturing | −0.48 | −0.51 | 0.68 | 0.51 |
| Land Allocation | | | | |
| Upland food | −1.75 | −0.42 | 0.65 | 0.35 |
| Treecrops | 1.09 | 0.26 | −0.40 | −0.22 |
| Input prices | | | | |
| Upland labor | −0.40 | 0.90 | 0.15 | 0.08 |
| Lowland labor | 0.64 | 0.68 | 0.43 | −0.68 |
| Upland land | 0.25 | 1.06 | −0.09 | −0.05 |
| Lowland land | 1.12 | 1.19 | −0.24 | −1.19 |
| Mfg. capital | −0.32 | −0.34 | −0.22 | 0.34 |
| | | | | |
| Food price | −0.08 | 0.98 | 0.03 | −0.99 |
| | | | | |
| Food demand | 0.29 | −0.04 | 0.08 | 0.32 |
| | | | | |
| Real GNP | 0.34 | 0.19 | 0.22 | 0.16 |
| | | | | |

**Table 5: Effects of 1% changes in some exogenous variables under assumption of a unified labor market..**

| Endogenous Variable | Tech. prog. in lowland food | Tech. prog. in tree crops | Incr. in mfg. specific factor | Tech. prog in upland food |
|---|---|---|---|---|
| *Output* | Percentage changes | | | |
| Upland food | −2.03 | −0.28 | 0.47 | 1.64 |
| Lowland food | 1.21 | 0.08 | −0.10 | −0.19 |
| Treecrops | 1.01 | 1.33 | −0.51 | −0.09 |
| Manufacturing | −0.11 | −0.18 | 0.90 | 0.14 |
| *Labor Demand* | | | | |
| Upland food | −2.22 | −0.16 | 0.31 | 0.86 |
| Lowland food | 0.53 | 0.19 | −0.26 | −0.46 |
| Treecrops | 0.79 | 0.48 | −0.70 | 0.18 |
| Manufacturing | −0.34 | −0.54 | 0.71 | 0.41 |
| *Land Allocation* | | | | |
| Upland food | −1.85 | −0.39 | 0.62 | 0.42 |
| Treecrops | 1.15 | 0.25 | −0.39 | −0.26 |
| *Input prices* | | | | |
| Labor | 0.45 | 0.72 | 0.38 | −0.54 |
| Upland land | −0.28 | 1.18 | −0.24 | 0.34 |
| Lowland land | 1.51 | 1.10 | −0.14 | −1.47 |
| Mfg. capital | −0.23 | −0.36 | −0.19 | 0.27 |
| | | | | |
| Food price | 0.08 | 0.95 | 0.07 | −1.10 |
| | | | | |
| Food demand | 0.24 | −0.03 | 0.07 | 0.36 |
| | | | | |
| GNP at const prices | 0.29 | 0.20 | 0.20 | 0.20 |
| | | | | |

**Appendix: derivation of equation (29)**

This derivation of the Slutsky equation for food demand is adapted from a proof in Cassing and Warr (1985). Totally differentiating the definition of aggregate income in (9) for $N$ products and $M$ factors:

$$dY \equiv \sum_{j=1}^{N} (Y_j(A_j)dP_j + P_j dY_j(A_j)) \equiv \sum_{i=1}^{M} \left( X_i(A_{ij})dW_i + W_i dX_i X_i(A_{ij}) \right)$$

Suppose, for example, that there is Hicks-neutral technical progress in sector $j$. Then (since for neutral technical progress $A_j = A_{ij}$ for all $i$) at constant prices

$$\sum_{j=1}^{N} P_j dY_j = \sum_{i=1}^{M} W_i \frac{dX_i}{dA_j} dA_j$$

therefore

$$dY = Y_f dP_f + \sum_{i=1}^{M} W_i \frac{dX_i}{dA_j} dA_j . \qquad \text{(A-1)}$$

An expression for compensated food demand (17) can now be obtained by taking the total differential of (7) and substituting from (A-1):

$$dC_f = \frac{\partial C_f}{\partial P_f} dP_f + \frac{\partial C_f}{\partial Y}\left( Y_f dP_f + \sum_{i=1}^{M} W_i \frac{dX_i}{dA_j} dA_j \right),$$

then applying the Slutsky decomposition (an asterisk denotes the income-compensated change in consumption with respect to a price change):

$$dC_f = \left( \left( \frac{\partial C_f}{\partial P_f} \right)^* - C_f \frac{\partial C_f}{\partial Y} \right) dP_f + \frac{\partial C_f}{\partial Y}\left( Y_f dP_f + \sum_{i=1}^{M} W_i \frac{dX_i}{dA_j} dA_j \right),$$

$$= \left( \frac{\partial C_f}{\partial P_f} \right)^* dP_f + \frac{\partial C_f}{\partial Y}\left( Y_f - C_f \right) dP_f + \frac{\partial C_f}{\partial Y}\left( \sum_{i=1}^{M} W_i \frac{dX_i}{dA_j} dA_j \right).$$

Dividing through by $C_f$:

$$\frac{dC_f}{C_f} = -\eta \left[ \frac{dP_f}{P_f} \right] + \eta \sum_{i=1}^{M} \left[ \frac{W_i X_i}{C_f} \right] \left[ \frac{dX_i}{dA_j} \frac{A_j}{X_i} \right] \left[ \frac{dA_j}{A_j} \right],$$

where $\eta = -\frac{\partial C_f P_f}{\partial P_f C_f} = \frac{\partial C_f Y}{\partial Y C_f}$ is the elasticity of food demand. Equation (29) follows from this.

**Endnotes**

[1] Estimates of the costs of soil erosion are sparse and controversial but available figures suggest that such costs are quite large. The "most conservative" estimates for three African countries (Mali, Malawi and Burkina Faso) range from annual losses of 1.7% of GDP for Mali to 4.8% for Malawi and 8.8% for Burkina Faso (Barbier 1991). Soil erosion in Java, Indonesia has been estimated to cost the economy $US 340-400 million (about 0.5% of GDP) per year (World Bank 1990), while the gross loss to the Philippine economy attributable to grassland sheet erosion alone was put at about $US 100 million (0.2% of GDP) in 1988 (World Bank 1989).

[2] For a discussion of this issue stressing interactions between upland and lowland agriculture see Jayasuriya (1991).

[3] Problems of soil erosion and degradation are not confined to uplands, although it appears at present that most acute problems are associated with upland land use patterns.

[4] Annual soil losses from cultivation of annual crops can exceed those from stable tree crop systems by factors of fifty or more. See, for example, Aminuddin, Chow, and Ng 1991; Gregerson, Draper and Elz 1989; Repetto 1989, and for Philippine data, Delos Angeles 1991.

[5] This view of farmer behaviour has strong empirical support as shown by numerous supply response studies (Askari and Cummings 1976). Farmers are known to respond more to differential incentives among crops and change their land allocation patterns rather than shift out of agriculture altogether (Bale and Lutz 1981). Further, even during the last few decades there have been dramatic changes in the crops chosen for cultivation by farmers in even the most remote parts of developing countries as evidenced, for example, by massive expansions of rubber area in Thailand and southwest China and coffee in New Guinea.

[6] To focus on changing profitability and its impact on land allocation among crops, we assume that cultivation of a particular crop is associated with a given rate of soil erosion which cannot be altered; in other words we abstract from the possibility that changes in relative crop profitability would lead to changes in the level of investments in land conservation rather than in the areas

devoted to the competing crops. On similar grounds we ignore the related and potentially important effect of changing land values on soil conservation investments and hence on overall soil degradation. This is a complex problem and addressing it even in partial equilibrium would require a much more elaborate model.There is controversy regarding the effects of higher output prices on rates of soil degradation (Barrett 1991; Clarke 1991; Lipton 1987; LaFrance 1990; McConnell 1983; Repetto 1989). It is widely assumed that higher prices would raise incentives for soil conservation. However, higher output prices may exert two contradictory influences. They raise the value of farm land and raise incentives to improve land quality, but they also create greater incentives for more intensive land use. If price liberalization changes the relative prices of agricultural commodities - as it is very likely to because of differences in tax or subsidy rates - overall land degradation effects will also depend on differing levels of soil erosion associated with each commodity.

[7] See Coxhead and Warr (1991) for a model built along similar lines where a traded good with exogenously given price is produced with two different specific factors; the model presented here extends the earlier analysis to the case where the output price is endogenously determined.

[8] Empirically, some intermediate characterization of labor mobility is probably appropriate in the short run. Our purpose in using these polar labor market assumptions is to explore the significance of the labor market in determining price, income and resource allocation outcomes.

[9] Non-Hicks-neutral technical change in a sector is indicated by different values of $A_{ij}^*$ terms in that sector. Although we restrict our discussion to Hicks-neutral cases only, we retain the $A_{ij}^*$ terms throughout in order to provide a general description of technical progress.

[10] Until recently Philippine international trade in rice was controlled by a government monopoly. While long term rice price trends reflect those in world markets, the price in any one year is a function of domestic production, demand and storage. Similarly, most upland food crops are low-quality staple starches. They are rarely traded internationally and are generally poor substitutes for other internationally traded food commodities.

[11] To maintain the model's tractability and to focus on the interregional aspects of food production and demand we continue to maintain the dual labor market assumption in this section. We return to the unified labor market case in numerical simulations presented in section 3.

[12] This decline can be offset only by a rate of technical change sufficient to maintain upland food's competitiveness in the face of the rising productivity in lowland agriculture.

[13] The decline of upland food may be explained in another way. Expansion of lowland food attracts labor from manufacturing, causing output there to contract and (at constant food demand) imports to rise. Increased import spending has to be financed by higher exports, so tree crop output expands – at the expense of upland food production. The proportion of upland land devoted to tree crops must rise (and that to food fall) as a result of technical progress in lowland food. Whether we regard the observed changes in production and factor demand as stemming from the food market clearing condition or from the trade balance constraint is immaterial, since the satisfaction of one set of conditions implies satisfaction of the other (Dornbusch 1974).

[14] Immizerizing growth is ruled out by the small country assumption.

[15] The simulation software used was GEMPACK v.4.2 (Codsi and Pearson 1988).

[16] This "sensitivity elasticity" is defined as the elasticity of *the change in* an endogenous variable with respect to a change in the value of one parameter, for a given exogenous shock (Pagan and Shannon 1985). Complete tables of sensitivity elasticities for the simulations described in this paper are available from the authors.

[17] Of course, this results depends on our assumption that treecrop production is relatively land-intensive, and would be reversed by the alternative assumption, i.e. that upland food production is relatively land-intensive.

[18] This is not surprising in a second-best situation: if the effects of soil erosion confer externalities (as assumed in our discussion) then the removal of policy-induced price distortions need not be optimal.