EPTD DISCUSSION PAPER NO. 48

RURAL POPULATION GROWTH, AGRICULTURAL CHANGE AND NATURAL RESOURCE MANAGEMENT IN DEVELOPING COUNTRIES: A REVIEW OF HYPOTHESES AND SOME EVIDENCE FROM HONDURAS

John Pender

Environment and Production Technology Division

International Food Policy Research Institute
2033 K Street, N.W.
Washington, D.C. 20006 U.S.A.

August 1999

ABSTRACT

This paper reviews hypotheses about the impacts of rural population growth on agriculture and natural resource management in developing countries and the implications for productivity, poverty, and natural resource conditions. Impacts on household and collective decisions are considered, and it is argued that population growth is more likely to have negative impacts when there is no collective responses than when population growth induces infrastructure development, collective action, institutional or organizational development. The impacts of population pressure, particularly on natural resource conditions, may be very different in different contexts, depending on the nature of local markets, institutions, and other factors. Thus careful and comparative empirical work is needed in different contexts before general conclusions can be drawn. There is still a lack of such empirical evidence.

The results of one study in central Honduras are used to examine some of the hypotheses presented. The results support neo-Malthusian concerns about the effects of population growth on land degradation, but also provide some support to Boserupian predictions that population pressure will induce adoption of labor-intensive land improvements, collective action to manage natural resources, and organizational development. In general, however, the impacts of population pressure were found to be relatively small and other factors, including infrastructure development and technical assistance programs, had stronger impacts on agricultural change and natural resource management. Although induced innovation theory argues that population pressure may induce such policy responses, we found that these interventions were more likely in less-densely populated communities. This emphasizes that such "induced" policy responses to population pressure do not happen automatically.

CONTENTS

Rural Population Growth, Agricultural Change and Natural Resource Management in Developing Countries: A Review of Hypotheses and Some Evidence From Honduras

John Pender*

1. INTRODUCTION

The impacts of population growth on agriculture and natural resource management have been debated at least since the time of Malthus. Although the dismal predictions of Malthus regarding the inability of agricultural production to keep pace with population growth have not come to pass in the industrialized nations, agricultural production per capita has fallen and poverty has increased in many developing countries in recent decades (especially in Africa). In addition, there are serious and growing concerns about the impacts of rapid population growth on natural resources, including forests, land, water, biodiversity, and other resources (World Commission on Environment and Development, 1987; Ehrlich and Ehrlich 1990).

In contrast to the dire predictions of the neo-Malthusian perspective, a more optimistic perspective has arisen in recent decades as well, following from the work of Ester Boserup and others Boserup (1965, 1981), Ruthenberg (1980) and others have emphasized the responses of households, communities and societies to pressures induced by population growth, including reduction in fallow periods, intensified use of labor and

---

* John Pender is a Research Fellow, Environment and Production Technology Division, International Food Policy Research Institute, Washington, D.C.

capital per unit of land, development and adoption of labor-intensive technologies, and institutional changes (such as development of more specific and individual property rights and development of markets). It is generally accepted that such responses, to the extent that they occur, should increase agricultural production per unit of land, though their impacts on labor productivity, output per capita and poverty have been debated (e.g., Robinson and Schutjer, 1984; Salehi-Isfahani, 1988; Krautkraemer, 1994). The impacts on natural resources are also debated (Blaikie and Brookfield, 1987; Lele and Stone, 1989; Panayotou, 1994).

The evidence on these issues is mixed. For example, an often cited study of the Machakos district in Kenya found that between the 1930's and the 1990's, per capita income had increased, erosion was much better controlled, and trees were more prevalent in the landscape, despite a five-fold increase in population (Tiffen, Mortimore and Gichuki, 1994), supporting the Boserup perspective. Numerous other studies have also found positive associations between population growth, agricultural intensification and investments in land improvement and resource conservation (see Templeton and Scherr, 1997, and the references cited therein). However, many studies have also found population growth to be associated with various aspects of resource degradation, including deforestation, overgrazing, soil erosion, soil nutrient depletion, and other problems (see studies cited by Templeton and Scherr; Panayotou, 1994; Kates and Haarmann, 1992).

Part of the difficulty in reaching definitive conclusions about the relationship between population growth and natural resource conditions is due to the fact that there are many complex and interdependent ways in which population growth may affect agricultural and natural resource management decisions by households, communities and societies. Population growth may affect natural resource management by affecting household decisions about land use, labor or capital intensity, product choice, technology adoption, off-farm employment, migration, or fertility (Bilsborrow and Carr, 1998; Panayotou, 1994; Boserup, 1965). It may affect natural resource management by affecting community and societal decisions relating to collective management of common property resources (Baland and Platteau 1996); development or adaptation of technology (Boserup 1965; Hayami and Ruttan 1985); investments in infrastructure (Ibid.); development of property rights, land tenure relations, markets or other institutions (Ibid.; North, 1990; Scherr and Hazell, 1994); or development of organizations (Pender and Scherr, 1999).

By affecting poverty, distribution of wealth, or other outcomes, population growth may also cause changes in resource management through feedback effects from these outcomes. For example, poverty may increase resource degradation by causing people to have a short time horizon in their decisions (Pender 1996; Holden, Shiferaw and Wik 1998), or may promote labor-intensive investments in resource conservation by farmers who have few alternative investment opportunities or low opportunity cost of family labor (Pender and Kerr, 1998).

Adding to the complexity of the issue is the fact that the impacts of population growth likely depend on many site-specific conditioning factors, such as agricultural potential, fragility of the resource base, market integration, initial population density, local human and social capital endowments, and other factors (Pender, Place and Ehui, 1999; Pender, Scherr, and Duron, 1999; Lopez, 1998; Tiffen, et al. 1994; Panayotou, 1994). Moreover, resource degradation or improvement is a multi-dimensional and site-specific concept; improvements in one type of resource or in resources in one location may be associated with degradation of other resources or resources in another location. For example, intensification of crop production may reduce pressure on forests but increase problems of soil erosion and nutrient depletion; enclosures of common grazing areas may lead to regeneration in enclosed areas but more rapid degradation of other grazing areas.

The purpose of this chapter is to sort through these complexities by reviewing key hypotheses about the impacts of rural population growth on agriculture, natural resource management, and related impacts on poverty in developing countries. I will consider factors conditioning the hypotheses, different aspects of resource management, and some of the evidence available with respect to these hypotheses. The emphasis of this paper is on the impacts of rural population growth. I do not consider in detail the broader set of linkages resulting from urban population growth, industrial development and the feedback effects on the agricultural and rural sectors. I have not conducted an exhaustive literature review of the evidence, but rely on some of the excellent literature reviews that have recently been completed (e.g., Templeton and Scherr, 1997; Panayotou, 1994). I then present results of recent field research conducted by the International Food Policy Research Institute on some of these issues in central Honduras, which represents a case of relatively low population density but rapid population growth.

2. HOUSEHOLD RESPONSES TO RURAL POPULATION GROWTH

I will proceed by considering possible responses to rural population growth, beginning with those that involve the least departure from the ways of doing things in the past (e.g., extensification of agriculture using the same methods), and considering later those that involve more investment, collective action and/or reorganization of social relations (e.g., changes in institutions such as property rights). A general hypothesis consistent with the evolutionary perspective of Boserup is that the responses requiring greater investment and accommodation are likely to come later, though this may not always hold if the pressures for change are very rapid or sudden, or if certain favorable factors exist (e.g., the opening up of a road may create a sudden increase in demand for private land titles, and this may be fulfilled if a land titling program happens to be already in place).

I consider responses mainly at the household and local community level. This is not to assert that responses occur only at these levels. Responses of course occur at the individual level, and household production decisions may not be adequately reflected by a unitary household model (Udry, 1996). Important responses are also made above the community level; e.g., by policy makers. I abstract from those complications to keep the task manageable, though this is not to argue that these other levels are unimportant.

For each type of response, I propose hypotheses about the factors favoring or inhibiting it, and the expected impacts of the response on indicators of agricultural productivity (including land productivity and labor productivity), human welfare (income and welfare per capita and distribution of welfare), and natural resource conditions (including impacts on forests, soil erosion, soil fertility, water availability and quality). Many other indicators of natural resource conditions (such as biodiversity) or human welfare (such as per capita food consumption) could also be suggested; I do not consider them for reasons of space and the possibility that the impacts on these may be largely reflected in the indicators mentioned. For example, the qualitative direction of impacts on biodiversity may be very similar to the impacts on forests.

The general types of household level responses to rural population growth include extensification of agricultural production using traditional methods, intensification of labor per unit of land using traditional methods (i.e., shortening fallow cycles), adoption of more labor-intensive methods of production (e.g., hand hoeing and weeding, mulching, composting), labor-intensive investments in land (e.g., soil and water conservation structures), adoption of capital intensive methods (e.g., use of draft animals, equipment, purchased agricultural inputs), knowledge intensive responses (e.g., development or adaptation of new techniques, such as biological conservation measures, integrated pest management, or integrated soil nutrient management), changes in product mix (e.g., adoption of more labor-intensive crops, integration of crops with livestock products, adoption of higher value products), changes in occupation (e.g., development of off-farm income), migration, and reduction in fertility. The hypotheses about these responses are summarized in Table 1.

Table 1 Hypotheses about household responses to rural population growth

Response	Conditioning Factors	Productivity		Human Welfare			Natural Resource Conditions			
		Land	Labor	Income /Capita	Welfare/ Capita	Dist. of Welfare	Forest	Soil Erosion	Soil Fertility	Water
Extensification	- Low population density - Open access land available and accessible - Land relatively homogeneous in quality	0	0	0	0	0	-	-	0/-	-
Shorter fallow	- Rising population density - Open access land becoming unavailable - Emphasis first on better quality land - Alternative opportunities for labor limited	-	-	0/-	-	0/-	-	-	-	-
Labor-intensive practices	- Rising population density - Open access land becoming unavailable - Emphasis first on better quality land - Alternative opportunities for labor limited	0	-	0/-	-	0/-	0	0	0/+	+/-
Labor-intensive land investments - near term	- High population density - Land tenure security - Agroecological suitability - Commercialization (+/-) - Off-farm opportunities (+/-) - Land market development - Access to credit - Poverty	0/-	-	0/-	-	+/-	0	0/+	0/+	+/-
Labor-intensive land investments – long term	(same)	0	0	0	0	+/-	0	0	0	+/-

Table 1 Hypotheses about household responses to rural population growth (continued)

Response	Conditioning Factors	Productivity		Human Welfare			Natural Resource Conditions			
		Land	Labor	Income /Capita	Welfare/ Capita	Dist. of Welfare	Forest	Soil Erosion	Soil Fertility	Water
Capital intensification – draft animals/plow	- Medium population density - Elimination of woody fallows, increased demand for bottomland with heavy soils - Climate and disease (humid tropics limit adoption) - Longer growing season or irrigation - Market access -Access to credit	0/+	0	0	0	0/-	-	-	+/0	-
Capital intensification – purchased inputs	- Complementarity to labor - Climate risks, irrigation - Access to roads, markets - Commercialization, production of high value crops - Access to credit -Government trade, exchange rate, marketing policies (+/-)	0/+	0/+	0	0	0/-	+/-	+/-	+/-	-
Knowledge intensification	- Changing factor scarcities (induced innovation hypothesis) - Growing population (reduces per capita costs of innovation) - Mechanisms to share costs of innovation or reward innovators for external benefits	0/+	0/+	0	0	0/-	+/-	0	0	0/+
Change in product mix- adoption of labor-intensive products	- Similar to factors affecting labor intensification	0	-	0/-	-	0/-	0/+	+/-	+/-	+/-
Change in product mix- increased specialization	- Higher population density - Development of infrastructure and markets	0	0/+	0	0	0/-	+/-	+/-	+/-	+/-

Table 1 Hypotheses about household responses to rural population growth (continued)

Response	Conditioning Factors	Productivity		Human Welfare			Natural Resource Conditions			
		Land	Labor	Income /Capita	Welfare/ Capita	Dist. of Welfare	Forest	Soil Erosion	Soil Fertility	Water
Changes in occupation/ Migration	- Education and training - Opportunities for labor in other occupations - Infrastructure development - Labor mobility - Land tenure security - Land and housing market development - Availability of social services in urban areas	-	0	0/+	0	0/+	0/+	+/-	+/-	+/-
Reduction in fertility-effects on age structure	- Costs and availability of education, food, health care - Expected wage levels - Availability of open access resources - Property rights/land tenure arrangements - Means to assure security in old age - Education and status of women; family planning	-	0	0/+	0	+/-	0/+	+/-	+/-	0/+

EXTENSIFICATION

Extensification of agricultural production using traditional methods of shifting cultivation is the first response one would expect to population growth in situations of low population density with large amounts of open access land available, of relatively good quality for agricultural production, and relatively accessible (Boserup, 1965; Binswanger and McIntire 1987). All of the conditioning factors are important. There are many situations (most common in Latin America) of low population density where agricultural expansion by smallholders is not possible because most suitable and accessible land is owned and protected by large farmers or ranchers. There are also many places where open access land exists, but agricultural expansion is limited because they are not well suited to agriculture (e.g., much of the humid tropics of Africa, where problems of pests and disease inhibit agricultural expansion) and/or remote (e.g., much of the Amazon region). In most areas of high population density, little open access land usually remains. An exception is where state or community ownership of land prevails but is not well enforced, leading to a situation of *de facto* open access. This situation is common in many state forests in developing countries (Otsuka, 1998). Not surprisingly, such forests are rapidly disappearing.

Where extensification is possible and the available land is relatively suitable for agricultural production, extensification is expected to have little impact on agricultural productivity per unit of land used or per unit of labor. In this situation, there will also be little impact on income per capita (including the value of subsistence production) or the distribution of income, since land of suitable quality is available to all. The main impacts of this response will be on resource conditions, and these will mainly be negative. Forest resources will be depleted as agriculture expands. In hilly terrain, this will likely lead to increased soil erosion as land cover is reduced through slash and burn. The reduction in forest cover and increase in soil erosion can lead to reduced availability of water in the local ecosystem by increasing runoff, and reducing the capacity of the ecosystem to store and recycle water through uptake by plants and evapotranspiration. Erosion and runoff can reduce the quality of water downstream and cause increased problems of flooding and sedimentation of rivers and reservoirs. Soil fertility will decline as a result of erosion, leaching and crop production without full recycling of the nutrients. However, fertility can again recover provided that the cropping cycle is short enough and the fallow cycle long enough to allow woody fallow to return (Vasey, 1979).

Once extensification has proceeded to where the land available is less suitable for agricultural production, further extensification may be slowed and farmers may have incentive to intensify production on the better quality lands instead. To the extent extensification continues to be pursued, it is likely where it is a lower cost option to intensification, though production costs likely will be higher than where land is of better quality. This is because farmers may have to work harder to clear the land, clear more land to achieve the same production, or plant crops for a shorter period due to more rapidly declining fertility. Production per unit of land cropped is likely to fall (especially in the second case), as is production per unit of labor (in all cases). Although productivity is likely to fall, production per capita may not, since farmers may work harder to maintain subsistence consumption. As long as this response is possible and continues, there will be little impact on income per capita or its distribution, although household welfare will decline as a result of lower labor productivity and increased labor input. The qualitative effects on resources will be similar to the effects discussed above for the case of uniform land quality, except that the magnitude of effects are likely to become greater as extensification proceeds into lands that are more susceptible to degradation, such as steeply sloping lands, or lands where soil fertility is low or apt to decline rapidly.

In summary, extensification likely represents the least cost response to population pressure from the farmers' perspective, where open access land of suitable quality is available and accessible. The costs in terms of depletion of unpriced resources may be very large, however. These costs, as well as the costs to the farmer, are expected to rise as such land begins to be used up, and lower quality or more remote land must be used. As population continues to increase, the costs of continuing expansion eventually become greater than the costs of more intensive production on better quality or more accessible land, and intensification eventually begins to occur. Of course, there may still be land available for extensification (though at higher cost), and as intensification proceeds and as the costs of this strategy rises, some extensification may continue to occur. Thus, intensification and extensification may occur simultaneously for some time, as long as some open access land is still available.

SHORTENING THE FALLOW CYCLE

When intensification first begins, farmers are likely to simply shorten the fallow cycle on better quality (or less remote) lands, returning to them sooner rather than expanding to lower quality lands (Boserup, 1965). As fallow periods shorten, forest fallow is eventually replaced by bush and then grass fallow, since the forest is not given time to regenerate.[1] Soil fertility is given less chance to recover, and the length of the cropping period must also be reduced.

The factors favoring this change are mainly the rising population density and declining availability of good quality land where extensification can occur. Insecurity of future access to better quality lands may accelerate the process, since land left fallow may be claimed by other users (Otsuka 1998). A factor that may inhibit this change (or any of the other aspects of labor intensification discussed below) is the availability of more remunerative opportunities for labor elsewhere. If there are opportunities to migrate to take advantage of available land elsewhere (extensification) or off-farm employment opportunities (locally or through migration), the process of intensification may proceed slowly or be halted by the flow of labor out of agriculture. We have examined the implications of the extensification strategy above, and will consider the off-farm employment and migration strategies later.

---

[1] This, of course, applies only to areas where the original climax vegetation is forest. Where the original vegetation is bush or grassland, declining fallow periods would still be expected to alter the original vegetative composition and to lead to declining soil fertility.

This strategy will lead to declining land productivity, due to declining soil fertility. There may be offsetting impacts on labor productivity, since declining productivity due to declining soil fertility may be offset to some extent by the reduced labor requirement to clear fallow fields, which will have less vegetation to clear (Vasey). However, one would expect farmers to have voluntarily reduced fallow periods earlier, if doing so increased labor productivity (since labor is likely the constraining factor in an extensive fallow system). Thus, our expectation is that if population pressure forces farmers to reduce fallow periods, the declining productivity effect outweighs the labor saving effect, and labor productivity will begin to decline. As long as there is still sufficient land available, however, production per capita can still be maintained if each farmer cultivates more land, and thus there may not be distributional effects on production and income per capita. Since cultivating more land with lower labor productivity requires more effort, farmer welfare decreases however.

Many of the expected impacts of shorter fallow cycles on resource conditions are similar to the impacts of extensification. To the extent that forest fallow existed prior to shortening the fallow cycle, this shortening will lead to less forest fallow land, which is likely to have similar impacts to a reduction in primary forest. Forest fallow can serve many of the same environmental functions as primary forests, including preventing soil erosion, recycling water and nutrients, and preserving biodiversity. The expansion of crop land relative to fallow of any kind increases the rate of soil nutrient depletion and possibly of soil erosion, since most types of fallow likely provide better vegetative cover of the soil than most crops (possibly excluding some perennial crops) during periods of erosive rainfall.

ADOPTION OF MORE LABOR-INTENSIVE METHODS

At higher levels of population density, and low levels of wages and off-farm opportunities, adoption of more labor-intensive methods of agricultural production begin to become economical. Use of hoeing and hand weeding can replace burning to clear crop fields, both because vegetation is reduced by declining fallow periods, and because the amount of labor available per unit of land is rising. Planting density may increase, as may the care given to planted crops through various labor-intensive methods to improve soil fertility, such as application of compost or mulch.

Greater labor intensity likely increases productivity per unit of land, but reduces labor productivity as a result of diminishing returns to labor (unless complemented by increased capital intensity or technical change, as discussed below). As with shortening fallow periods, farmers may compensate for reduced labor productivity by working harder, so that production and income per capita do not decline. Again, however, welfare does decline as a result of declining labor productivity. As land becomes increasingly scarce, the distributional impacts of access to better quality land increase, with greater welfare achieved by occupants of the better quality land, as predicted by the Ricardian theory of rent.

The impacts of increased labor intensity on resource conditions may be mixed, though generally positive. More intensive practices and reduced use of burning will reduce the rate of deforestation and the problems associated with it. These also may result in greater vegetative cover being kept on the land (relative to the impacts of burning), reducing problems of erosion. Adoption of labor-intensive soil fertility management practices may improve soil fertility, though these may be insufficient to offset the increased outflow of soil nutrients resulting from increased amounts harvested per unit of land (Smaling, 1998; Buresh, Sanchez and Calhoun 1997).

LABOR-INTENSIVE INVESTMENT IN LAND

Rising population density and declining value of labor relative to land also may lead to labor-intensive investments in land improvement, such as construction of terraces, bunds, check dams, live barriers, or other structures to conserve soil and water. Land tenure security is likely a critical conditioning factor for such investments. Without secure tenure, farmers risk losing the benefits of such investments and thus may not make them even if the potential benefits are high (Feder, et al. 1988). The impact of tenure insecurity may be reversed, however, if the act of making such investments actually increases tenure security (Otsuka, 1998; Besley, 1995).

Other factors conditioning such an investment response include agroecological conditions, the extent of commercialization, the extent of off-farm opportunities, the nature of local factor markets (especially for land, labor and credit), and poverty.

Agroecological conditions may have more effect on the types of investments that become economical than on whether land improvements eventually occur as population pressure increases. For example, in drier environments, live barriers may have difficulties in becoming established or may compete with crops for water, whereas physical structures such as stone or soil bunds may yield high benefits (Herweg 1993). In more humid environments, by contrast, such physical structures may be less effective than biological approaches.

Commercialization may have mixed effects on land improvements. On one hand, it increases the value of land, but on the other it may also increase the value of labor. The net effect on the relative value of land to labor will determine whether commercialization promotes or inhibits labor-intensive land improvements. Similarly, commodity prices have ambiguous effects on land improvements and land degradation (LaFrance, 1992; Pagiola, 1996).

Off-farm opportunities likely increase the value of labor and thus tend to inhibit labor-intensive investments (Pender and Kerr, 1998; Clay, Reardon and Kangasniemi, 1998). On the other hand, off-farm income tends to increase farmers' liquidity and reduce their discount rates thus tending to promote investments, particularly where there is a functioning labor market (Ibid.).

The existence of a land market may promote land improvements by reducing the irreversibility associated with such investments (since farmers would have the option to recoup some or all of the value of their investment by selling or leasing the land) (Pender and Kerr, 1999). A land market and the ability to mortgage land may also promote investment by increasing farmers' access to credit (Feder, et al., 1988; Pender and Kerr, 1999). Credit constraints may cause farmers to have high discount rates, thus reducing incentives to invest in land improvements with high initial costs and limited near term benefit (Pender, 1996; Holden, et al. 1998).

Poverty may have the same effect of shortening farmers' time horizons (Ibid.). On the other hand, poorer farmers may be more likely to invest in labor-intensive land improvement because the opportunity cost of their time is lower (Pender and Kerr 1998) or because they have fewer profitable alternative investment alternatives.

Such land improvements can be expected to eventually increase land and labor productivity (else they would not be voluntarily adopted by farmers). However, they may reduce production in the near term by displacing land that otherwise would have been used in production. Thus they may lead to reduced production per capita in the near term but higher production per capita in the longer term. They may also reduce farmers' ability to take advantage of off-farm employment opportunities, because of the labor required to construct and maintain them, thus reducing off-farm income. The distributional impacts of such investments depend mainly on who is able to benefit from them, as determined by the conditioning factors noted above. If poverty and credit constraints are major factors inhibiting such investment, then the distribution of income and wealth may become more unequal as a result of differences in investment between rich and poor. On the other hand, distribution may become more equal if poorer people are more able to make such investments because of the lower opportunity costs of their time.

The impacts of labor-intensive land improvements on resource conditions are likely positive in general, though this may not always be the case. Such investments can help to reduce erosion, reclaim degraded land, and reduce pressure on more marginal lands. By helping to reduce erosion, they may reduce the outflow of soil nutrients and give farmers greater incentive to use fertilizers, manure, or other means of improving soil fertility (to the extent that such investments and soil fertility measures are complementary). By helping to control runoff and conserve soil moisture, they can help to recharge groundwater aquifers, contribute to regeneration of vegetation, and reduce problems of flooding downstream. However, such investments can also contribute to problems such as accelerated runoff and downstream erosion if not properly planned or maintained. For example, investments in drainage from one farmer's fields may channel runoff into a neighbor's fields or accelerate the rate of flow downstream. Poorly constructed or maintained bunds or other barriers may concentrate water flows and lead to gully formation. Conversely, water harvesting structures may increase the availability of water to farmers who have constructed them at the expense of downstream water users. Thus, achieving positive net social (as opposed to private) benefits of such investments may require collective action at the village level or higher, to assure that such externalities are taken into account.

ADOPTION OF CAPITAL INTENSIVE METHODS

Population growth may stimulate adoption of capital intensive methods of production as well, particularly those that are complementary to labor (i.e., their productivity is greater when combined with more labor input). This may include use of draft animals and farm equipment, and some types of purchased inputs. The factors conditioning these and their impacts may be different, so I consider them separately.

The use of draft animals and plows is likely after population density has reached a high enough level that forest or bush fallow are no longer practiced (Pingali, Bigot and Binswanger, 1987). In these systems, the costs of removing tree stumps and maintenance of animals is high, relative to the costs of using fire and hand implements to prepare fields. Once the transition to grass fallow has occurred, the costs of using animals and plows are substantially reduced. At the same time, the value of manure as a source of soil fertility rises as fallow periods become shorter, and the availability of grass as a fodder source increases, so that the benefits of using animals rises. Another factor promoting increased use of animal power and plowing is increased use of bottomlands with heavy soils as a result of population pressure.

Other factors that condition the transition to animal draft power include climate and disease constraints, soil conditions, market access and the extent of commercialization, and the availability of credit. In humid tropical climates, adoption of draft animals is often prevented by tropical diseases, such as trypanosomiasis in humid sub-Saharan Africa (McIntire, Bourzat and Pingali, 1992). Adoption likely occurs earlier where the growing season is longer or irrigation is possible, allowing for greater capacity utilization of draft animals and equipment (Pingali, et al. 1987). Adoption also likely occurs earlier where soils are heavier, as noted above. Where markets access is good and prices of meat are attractive, the returns to raising animals for meat as well as draft power may promote earlier adoption (Ibid.). Access to credit to finance animal purchases may also promote earlier adoption of draft animals and plows, where other factors assure that their use is profitable.

Adoption of draft animals and plowing does not necessarily increase land productivity, but it increases labor productivity by reducing labor requirements per unit of land (Ibid.). If additional land is available or land can be used more intensively (for example through irrigation and multiple cropping), the increase in labor productivity can lead to an increase in agricultural output per capita. Agricultural output per capita may also rise if labor is able to migrate out of agriculture as a result of the labor savings. Even without an increase in production per capita of a given crop, the value of output per capita may rise if the labor savings enables farmers to shift into higher value crops which may require more labor and plowing. Per capita incomes may increase even without an increase in the value of per capita production, since labor saved may be employed in off-farm activities. Farmers' welfare may thus increase because of greater value of production, off-farm income, leisure, or a combination of the three. The distribution of welfare benefits may be quite unequal, however, depending upon differences in farmers' abilities to finance acquisition and maintenance of animals and implements, and in the amount of land they operate, which will determine the extent of capacity utilization.

After the initial benefits of adoption of draft animals and plows are realized, further intensification of their use resulting from further population growth is likely to eventually face diminishing returns (holding technology constant). Thus income and welfare per capita are not likely to continue to rise as population continues to grow, unless this induces technological or other changes as discussed below.

The impacts of adoption of draft animals and plowing on resource conditions are complex and mixed. Animal manure can contribute to soil fertility, though this may be merely recycling nutrients, if the animals are fed only crop residues and grass from farmers' own fields. To the extent that animals graze or are fed materials from outside the farm and their manure is kept on the farm, this represents a net addition to the fertility of the soil on the farm, though this may be at the expense of soil fertility on common grazing lands. As livestock populations grow, overuse of such common grazing lands may occur, particularly if their use is not adequately regulated, leading to declining productivity of the commons. Overgrazing can also cause serious problems of soil compaction and erosion. Plowing also can cause serious erosion problems, especially on sloping lands, if adequate measures are not used to prevent it. The demand for fodder for growing livestock herds may induce further deforestation to clear land for grazing. Increasing animal numbers also increases demands on available water supplies and can cause water pollution problems resulting from animal wastes. At the same time, the labor saving provided by use of draft animals can enable farmers to invest more effort in soil and water conservation measures; while the animals may contribute labor to such efforts as well.

Adoption of purchased inputs, such as chemical fertilizer, improved seeds, and pesticides may be influenced in complex ways by population growth. To the extent such inputs are complementary to labor, one would expect population growth to promote their adoption. This may be the case with chemical fertilizer and improved seeds, though the evidence is not clear on these. Herbicides are more likely to be substitutes for labor, so one would not expect population growth to promote their use, unless population growth induces a change in farming system that favors their use. For example, the transition from forest to grass fallows and sedentary farming may favor adoption of herbicides, since they may be more cost effective than burning to control weeds in the latter types of situations. In addition, problems of weeds and pests may increase as agricultural intensification proceeds, as a result of declining soil fertility and diminished habitat for the natural predators of pests. Thus, even for inputs that are not complementary to labor, there may be an increase in demand for their use as population grows.

Farmers' incentive and ability to use purchased inputs in response to population growth is largely conditioned by the returns to and risks of such inputs (determined by agroclimatic factors, crop choice, and management practices) and the costs, accessibility, and ability to purchase these inputs (determined by market access, extent of commercialization, development of the input market, government policies, access to credit and/or off-farm income, and poverty). In drought-prone areas, use of chemical fertilizers can be very risky, unless adequate soil moisture can be assured through irrigation, water conservation, or other methods. Returns to use of such inputs will generally be higher with higher value or higher yielding crops. In addition, many such crops may be more susceptible to damage by insects or weeds than more traditional varieties, thus generating greater demand for pesticides. Commercial production of cash crops also facilitates access to the income needed to purchase such inputs. This is of course dependent upon access to markets, which also increases the availability and reduces the costs of inputs. Development of a competitive input market also facilitates use of inputs. Government policies, particularly those relating to foreign trade, exchange rates, input subsidies and distribution, and regulation of importers, wholesalers and retailers of agricultural inputs, can have a large impact on the development of the input market and the availability and cost of such inputs. Farmers' access to credit and/or off-farm income may determine whether and how much they are able to purchase of inputs. Without sufficient access to credit (and even with it), poverty may prevent farmers from taking advantage of profitable opportunities to use inputs, due to financial constraints as well as extreme risk aversion.

The expected impact of such inputs, where adopted, is to increase land and/or labor productivity. To the extent that both are increased (e.g., by improved seeds and fertilizer), agricultural production per capita is likely to increase. Labor saving inputs such as herbicides may not increase land productivity directly, though the labor saved may be used to increase land productivity by more intensive labor use in other crop activities. Use of purchased inputs may also enable production of higher value crops, thus increasing the value of output per capita. These effects will lead to increased average welfare per capita among farmers, compared to what would occur without adoption of such inputs. The distribution of the benefits may be very unequal, however, depending upon differential access to suitable land, markets, credit and/or sufficient income to finance such purchases.

It should be emphasized that the increase in per capita income resulting from such capital intensification flow from the increase in capital used per farmer, and not from population growth itself. Improved access to markets and commercialization can induce adoption of such practices without rural population growth, and population growth reduces the amount of capital used per worker if production is diminishing returns to scale (Pender, 1998). Even in the case of constant returns to scale, a faster population growth leads to less steady state capital intensity per worker than a slower growth rate (Ibid.; Solow, 1956). Thus population growth beyond the point which induces adoption of new capital intensive technology is not expected to lead to welfare benefits (unless the technology exhibits increasing returns to scale), even though the adoption of such technology may yield welfare benefits.

The expected impacts of purchased inputs on natural resources are mixed. Increased use of chemical fertilizers can improve soil fertility, especially if used in conjunction with measures to preserve or restore soil organic matter (Sanchez, et al. 1997). The use of such valuable inputs can also increase farmers' incentive to control soil erosion, lest such valuable inputs be washed away. The additional crop residue and other biomass made available through improved soil conditions (as well as improved seeds) may reduce the pressure on grazing lands and forests, by providing alternative sources of fodder and fuel. Additional fodder availability may in turn allow greater use of animals, which may further improve soil fertility through manure availability. Thus, such purchased inputs may help to catalyze a virtuous cycle of soil improvement and productivity enhancement. On the other hand, if farmers use purchased inputs as a substitute for efforts to improve soil conditions more generally, their use may only mask the effects of land degradation. In this case, the vicious cycle of land degradation, declining productivity, and poverty may continue unabated. In addition, increased use of agricultural chemicals (especially pesticides) without proper training and precautions can contribute to problems of water contamination, human health problems, species extinction, and other environmental problems.

KNOWLEDGE INTENSIFICATION

Increasing the "knowledge intensity" of agriculture, by invention of new production technologies or adaptation of existing techniques to new conditions, is another possible response to population pressure or other pressures. The induced technical innovation hypothesis (Hayami and Ruttan, 1985) posits that technical innovation taking advantage of relatively abundant factors will be induced by changes in relative factor endowments. In much of the literature on induced technical innovation, innovation is seen as being supplied primarily by agricultural research organizations. However, farmers themselves may also be important sources of technical innovation (Boserup, 1965, 1981; Richards, 1985). For example, population growth may induce farmers to invent or adapt labor (and knowledge) intensive methods, such as new indigenous soil and water conservation measures, new organic soil fertility management practices, or integrated pest management approaches. It is difficult to draw a clear distinction between knowledge intensification and simple changes in factor intensity, since many changes in labor or capital intensity involve a strong element of adaptation and learning by doing. Similarly, changes in product choice or occupation (discussed below) also involve learning and adaptation, and thus some degree of knowledge intensification.

Although the distinction between induced technical change and simple changes in factor proportions is difficult to draw in many practical situations, the conceptual distinction is important. In the absence of some learning or invention, constant or diminishing returns to scale in agriculture will imply that labor and capital intensification will be insufficient to improve human welfare as population grows (Pender 1998). However, the nonrival nature of new knowledge, and positive externalities associated with investments in human capital and learning by doing, can cause increasing returns to scale, providing the basis for sustainable long term growth in incomes and welfare per capita (Romer 1990; Lucas 1988; Arrow, 1962). If there are increasing returns to scale, population growth may contribute to more rapid technical change and welfare improvement if it enables economies of scale and specialization to be realized.[2] For example, the per capita costs of inventing a new method of production will decline with population growth, since the total costs of such invention are likely unaffected by population growth. If mechanisms are in place (or are induced to develop) to share such

---

[2] Recall Adam Smith's famous dictum: "The division of labor is limited by the extent of the market".

costs or internalize the external benefits among a growing population, technical innovation is likely to occur simply because the per capita costs are declining.

Whether population growth does in fact lead to technical innovation thus depends critically upon whether institutional or organizational mechanisms exist to allow such economies of scale and positive externalities to be realized. One way to do this is by taxing people to pay for the costs of agricultural research or experimentation. This is of course an important response at the national or state level, but is likely limited at the local level. Sharing costs and risks of innovation at the local level may occur through local farmer organizations, such as community mutual support groups or savings and credit groups that serve to pool risks. Another approach is to compensate farmer innovators for some or all of the external benefits that arise from innovations. For many kinds of innovation in developed countries, this is done by assigning intellectual property rights (e.g., patents and copyrights). However, such formal mechanisms likely are of limited applicability to most of the subtle and often site-specific innovations that farmers in developing countries generate, and the transaction costs of such formal approaches are likely prohibitive. But less formal mechanisms to reward innovators may be quite important, such as providing them greater status in the community, prizes through local production contests, etc. Many factors affect the prospects for such institutional or organizational development. These factors are considered below in the discussion of collective responses.

The impacts of knowledge intensification in agriculture for agricultural productivity and human welfare are expected to be positive. Total factor productivity is expected to increase, so that the average productivity of labor, land, and capital may all increase. This can increase income per capita directly as well as by promoting greater investment in land and/or capital (since returns to investment will increase). The distribution of benefits will depend upon how (and how much) innovators are compensated, how widely knowledge of the innovation spreads, and how applicable the innovation is to different farmers' circumstances. Where innovators are compensated more through status or other non-economic mechanisms, where information is widely available, and where the innovation is applicable to a wide range of circumstances, the economic benefits of innovation will be more widely distributed.

The impacts of innovation on resource conditions will depend of course on the nature of the innovation as well as other factors, and may be mixed. For example, development of a new technology that increases the profitability of farming may reduce pressure on forests if the technology is more suited to labor-intensive production than to extensive production, if the elasticity of demand for food is low and the technology increases food production, or if labor supply is relatively inelastic (Angelsen and Kaimowitz, 1998). Conversely, if the technology reduces the cost of clearing forests or if factor supplies and output demand are elastic, the increased profitability of farming may lead to increased deforestation. To the extent that innovations are induced by factor scarcity, one would expect population growth to result in labor using, land saving innovations, which should promote land improvement. Soil fertility should therefore tend to be enhanced and soil erosion reduced by population induced innovation. However, as mentioned earlier, such land improvements will depend critically upon the security of land tenure, and on other factors such as local agroecological conditions and the extent of commercialization. Since scarcity of other resources such as water also increases with population growth, induced innovation is likely to emphasize conservation or improvement of water supplies as well.

CHANGES IN PRODUCT MIX

Population growth may also induce changes in the mix of products produced by farmers. Increases in labor to land ratios make adoption of products requiring greater labor intensity and producing higher returns per unit of land likely. At lower levels of population density, population growth may induce a change from extensive livestock or cereal production to integrated crop-livestock systems that use labor more intensively and take advantage of complementarities between crop and livestock production (McIntire, et al., 1992). At higher levels of population density, further population growth may induce a return to specialization as a result of increasing competition between crops and livestock for land and water, and development of infrastructure and markets making specialization more profitable (Ibid.). Adoption of highly labor-intensive crops, such as rice or vegetables under irrigated conditions, may enable much fuller utilization of available land but leave less land or labor available for the maintenance of livestock (except perhaps draft animals). On the other hand, intensive livestock operations, such as commercial dairy or poultry operations, may develop in areas close to urban markets as population density rises to high levels.

Many of the factors conditioning the transition from specialized extensive crop or livestock production to integrated crop-livestock systems were discussed above, in discussing adoption of draft animals. Topography, soils, climate conditions and the extent of infrastructure and market development condition the comparative advantage of specialized crop or livestock production relative to integrated systems. Where topographic and/or soil conditions are not well suited to plowing (e.g., on steep slopes), adoption of draft animals may be limited. Good access to roads and urban markets, or significant local variations in comparative advantage, will favor continued specialization and trade as population grows, particularly at higher population densities where problems of competition between crops and livestock become more severe. The transition to intensive irrigated crops of course depends upon the potential for irrigation as well as the availability of inputs such as fertilizer, seeds and pesticides, access to credit, and access to markets (particularly for perishable crops such as vegetables). Development of commercial dairy or poultry production depends upon the availability of low cost feed, as well as close proximity to markets. Particularly with perishable products such as milk or vegetables, development of organizations (such as cooperatives) or institutional mechanisms (such as contract farming) to ensure access to inputs and credit, an assured market for sellers, and quality control for buyers, may be very important.

As with adoption of more labor-intensive methods of production, adoption of more labor-intensive products can be expected to increase the value of output per unit of land, but may be associated with reduced value per unit of labor input, unless some element of learning or technological change is associated with the change in product mix. Where shifts in product mix are brought about by new opportunities, such as new technology, development of infrastructure, or expansion of markets for high value products, increases in the value of labor as well as land are likely. Only in such cases can one expect the shift in product mix to improve incomes per capita and welfare, and population growth will be responsible for the improvement only to the extent that it led to the expansion of such opportunities.

The impacts of changes in product mix on resources can be complex. The adoption of more labor-intensive products can be expected to reduce pressure on forests or other marginal lands, as long as the supply of labor is not perfectly elastic. Adoption of such products may involve better management of land in some respects. For example, investments in soil and water conservation structures may be promoted by adoption of irrigated crops (Pender and Kerr, 1998). On the other hand, continuous multiple cropping of such crops may create problems for soil fertility and structure, while frequent plowing may cause problems of severe soil erosion. Problems of soil fertility and structure may be aggravated as integrated crop-livestock systems are replaced by specialized crop production at high population density, since reduced availability of manure may reduce soil organic matter and nutrients. Farmers may compensate for reduced manure by using chemical fertilizers, but this may not address the problems associated with low soil organic matter. Increased use of fertilizers and pesticides in such intensive crop systems also may cause water quality and health problems, as mentioned previously.

CHANGES IN OCCUPATION AND MIGRATION

Declining land availability and labor productivity resulting from population growth may induce people to seek alternative sources of income. At the same time, development of infrastructure and markets, and the process of agricultural intensification itself may create new opportunities for non-farm employment. For example, adoption of plows or other implements will generate demand for tool makers. Opportunities for specialization and trade will increase as the size of the potential market grows, as originally argued by Adam Smith. While many opportunities may develop within rural communities, a large share of the new opportunities will likely occur in developing urban centers, facilitating rural to urban migration.

Key factors influencing this response include education and training opportunities, labor mobility, land tenure security, land and housing markets, the development of infrastructure, the pace of investment and growth in the industrial sector of the economy, the presence of social services in the urban sector, and poverty. Education and training are obviously important for more skilled occupations. Labor mobility is of course necessary for rural people to take advantage of non-farm employment opportunities in urban areas. Such mobility may be inhibited by explicit policies to restrict migration (e.g., requirements of residence permits), but may also be retarded by the absence of housing in urban areas, land tenure insecurity that may arise by leaving the rural area, limited ability to sell or lease out farmland, poor living conditions and social services in urban areas, or the risks associated with migration, which may be very high for very poor people. Many of these factors may cut the other way, however. Displaced people from rural areas may find it easier to establish squatters' rights in urban shantytowns than in less anonymous rural communities. Poverty and desperation may drive people to such areas, despite the risks. Urban biased policies, better social services and/or higher wages in urban areas may attract migrants to urban areas, even if unemployment is greater there (Lipton, 1977; Harris and Todaro, 1970).

Movement of labor out of agriculture and into other occupations can have positive impacts on productivity in agriculture. By reducing the stock of labor in agriculture, average productivity of the labor (but not of land) remaining in agriculture should increase, unless surplus labor exists in the agriculture sector (Lewis, 1954). To the extent that labor shifts into other occupations with productive linkages to agriculture (such as supplying tools or production inputs), this can also contribute to productivity improvement. By increasing off-farm demand for food and other agricultural products, migration out of agriculture can stimulate market development and increase relative prices of agricultural products, promoting investment in farm improvement. Off-farm employment by rural residents or by family members in urban areas can provide a source of income and savings to finance purchase of inputs or investments in agriculture (Reardon, Crawford and Kelly, 1994). These effects are expected to contribute to increased per capita incomes and generally increased welfare in rural areas. Distributional impacts will favor those with less or no land, since wages will tend to rise relative to land rents as a result of employment of labor outside of agriculture.

There can also be negative impacts on agriculture and resource management as well. As off-farm opportunities and rural wages increase, labor-intensive investments in land management and improvement become less attractive, and even existing investments may be less well maintained.[3] As a result, existing systems of production may become unsustainable, and a process of agricultural dis-intensification may occur (Goldman, 1995). The qualitative impacts of this on natural resource conditions may be the opposite of the impacts of agricultural intensification (both positive and negative). For example, labor-intensive methods of soil fertility management (such as composting or mulching) may be abandoned and soil and water conservation structures may not be maintained, contributing to reduced soil fertility and increased erosion in the near term. However, if dis-intensification leads to a return to longer-term fallows, it may result in regeneration of soil fertility and woody vegetation in the longer term. The point, well articulated by Goldman (Ibid.), is that changes in population density may change what constitutes sustainable agricultural practices. Once agricultural systems and practices adjust to the new circumstances, the system may again become sustainable, although substantial resource degradation may occur during the transition from one system to another.

[3] The effect of increased wages on land investment may be offset may the liquidity-enhancing effect of off-farm income, which may enable farmers with off-farm income to hire workers to make investments (Pender and Kerr, 1998; Clay, et al. 1998).

CHANGES IN HOUSEHOLD FERTILITY DECISIONS

The final household level response to population growth that I consider is change in household fertility decisions.[4] According to the modern economic theory of fertility decisions, fertility is determined by the interaction of demand and supply factors. Households' demand for children is influenced by the costs of raising, caring for, and educating children; the economic benefits that they may provide the household over their lifetime (including their contribution to household income and providing old age security for parents); and of course the non-economic benefits or costs that people associate with children (Becker and Lewis, 1974; Schultz, 1981). The supply of children is influenced by biological factors that may be influenced by the nutrition and health of women (Easterlin, 1980).

Population growth may have effects on both demand and supply factors, many of which suggest that population growth should induce declining fertility. If population growth results in lower wages and less available open access resources that can be readily exploited, the benefits of having many children may tend to decrease. As resource and food supplies become scarce, the costs of raising children are also increased. If population growth is a result of declining child mortality, parents will find that they need to have fewer children to ensure that some will survive, be productive and contribute to their old age security, and may decide to substitute "quality" for "quantity" (Becker and

[4] I do not consider mortality rates to be a choice variable for households, but rather something they try to minimize. Thus mortality rates may respond to population growth, as originally argued by Malthus, but are not properly considered a household behavioral response.

Lewis). To the extent that population growth increases poverty and reduces the nutrition and health of women, this may also induce declining fertility for biological reasons (Easterlin). Furthermore, if children are seen as an investment with near term costs and long term benefits, population-induced poverty may reduce fertility by increasing the discount rate and shortening households' time horizon.

However, there are many factors that may cause fertility rates not to decline as a response to population growth. Continuing poverty may cause parents to continue to desire a large number of children to ensure their old age security, even if child mortality rates fall. Children may be seen as more productive assets in farming than in other occupations; thus the demand for children may remain high as long as farming is the dominant activity of households. Agricultural intensification and technical change may increase the productive benefit of having children and thus slow the decline in fertility (Vosti, Witcover and Lipton, 1994). Low education levels and status of women may continue to foster early marriage and child-bearing. Lack of information or access to family planning options may limit the ability of households to convert a decline in demand for children to a decline in fertility. Religious and cultural norms about family size, land inheritance rules, and other socio-cultural factors may also inhibit a fertility response (Ibid.).

To the extent that a decline in fertility occurs as a result of population growth, this will tend to mitigate any of the impacts of increased population size discussed above. An additional effect is to change the age distribution of the population.[5] In the near term, a decline in fertility will reduce the dependency ratio, leading to increased production and welfare per capita. This will increase households' ability to save and invest, which also contributes to growth in income and welfare per capita. This increase in income and savings per capita will help to ensure the old age security of parents, and will be needed since they will have fewer children in the working population as a result of declining fertility. To the extent that parents invest in greater quality of education and health care of their children as a result of substituting "quality for quantity", there may be an intergenerational transfer of wealth from parents to children.

The impacts of the changing age structure following a decline in fertility on resources are likely to be generally positive, though there may be negative impacts as well. By enabling greater investment, this will encourage investment (per capita) in improved natural resources as well as other forms of capital, particularly if different forms of capital are complementary (Pender, 1998). Increased wealth per capita may reduce households' discount rates and increase their access to credit, and thus also promote investment in resources (Pender 1996). Increased investment in children's education may lead to a greater awareness of resource and environmental problems. On the other hand, increased wealth and education may cause people to have higher opportunity costs of labor and better alternative investment opportunities than to invest in

[5] The impact on age structure of an acceleration in population growth caused by a decline in mortality at the beginning of a demographic transition is just the reverse of the impact of a decline in fertility. The impacts of such a change in age structure will thus be the opposite of those considered here.

land or other resource improvement. The positive effects of the changing age structure and dependency ratio on investment in resource improvement may be offset by increasing wages, which will reduce incentives to make labor-intensive investments. Thus, as with most other responses, the predicted impacts of fertility decline on resource conditions are mixed.

3. COLLECTIVE RESPONSES TO RURAL POPULATION GROWTH

The responses to population growth that may occur at a community or higher level include investments in infrastructure, changes in collective action to manage resources (e.g., management of common property resources), changes in institutions (e.g., property rights and land tenure arrangements, development of markets), and changes in organization and social roles (e.g., establishment of organizations to protect common resources or achieve economies of scale in marketing). Our hypotheses about these responses are summarized in Table 2.

INVESTMENTS IN INFRASTRUCTURE

Investments in rural infrastructure may be promoted by population growth. The costs of infrastructure such as roads, irrigation systems, and electricity networks are largely fixed costs, so that the costs per capita decline as population grows (Boserup, 1965). As with technical innovation (discussed previously), the ability to take advantage of such economies of scale will depend critically upon the development of institutions and organizations. Thus, the development of cost sharing mechanisms, such as a tax system or collective investment in infrastructure development, is needed. The potential for local collective action to achieve these scale economies is of course much greater for investments that do not require much technical input or sophisticated capital (e.g., construction rural feeder roads or hand dug wells). A functioning system of public finance will be necessary to finance more technological and/or capital intensive projects such as large dams and electricity networks. The factors determining such institutional and organizational development (discussed below) are thus critical.

Infrastructure development (particularly roads and irrigation) can have large positive impacts on agricultural productivity and rural incomes by increasing access to and reducing costs of inputs, increasing farm level prices of outputs, providing access to irrigation water, enabling production of higher value perishable products, improving access to technical assistance and education, increasing specialization and trade, and increasing off-farm employment opportunities. Thus, rural welfare will tend to increase in general, though there may be adverse distributional impacts. Households with land

Table 2 Hypotheses about collective responses to rural population growth

Response	Conditioning Factors	Productivity		Human Welfare			Natural Resource Conditions			
		Land	Labor	Income /Capita	Welfare/ Capita	Dist. of Welfare	Forest	Soil Erosion	Soil Fertility	Water
Investments in infrastructure	- Growing population (reduced per capita costs) - Mechanisms to share costs (collective action, institutional and/or organizational development)	0	0	0	0	+/-	+/-	+/-	+/-	+/-
Collective action to manage resources	- Moderate population density (economies of scale in protection, diseconomies in collective management) - Moderate population growth (stability of resource users group) -Extent of externalities -Transaction costs of private bargaining -Number and heterogeneity of resource users -Geographic and social proximity of users - Time horizons of users - Risks and risk aversion - Norms of cooperation or equity - Presence of organizations	+/-	+/-	0	0	+/-	+/-	+/-	+/-	+/-

Table 2 Hypotheses about collective responses to rural population growth (continued)

Response	Conditioning Factors	Productivity		Human Welfare			Natural Resource Conditions			
		Land	Labor	Income /Capita	Welfare/ Capita	Dist. of Welfare	Forest	Soil Erosion	Soil Fertility	Water
Institutional change	- Changes in factor scarcity (induced institutional innovation) - Changes in technology/opportunities - Private costs and benefits of political entrepreneurs, powerful groups - Collective action and organizational change - Cultural factors (e.g., norms of equity, cooperation, religion, ideology) - Education	+/-	+/-	0	0	+/-	+/-	+/-	+/-	+/-
Organizational change	- Similar to factors affecting collective action and institutional change	+/-	+/-	0	0	+/-	+/-	+/-	+/-	+/-

displaced by road or irrigation projects may not be adequately compensated. Construction of irrigation projects may increase access to water for upstream users at the expense of downstream users. Differential access to roads or irrigation may increase the inequality of income, and promote acquisition of land or other resources by advantaged farmers at the expense of poorer ones. The extent to which such negative impacts arise and are compensated depends upon the nature of the process used to decide on, plan and implement them. The more the process includes potentially affected people, the more likely that negative distributional impacts can be avoided. There may be a trade-off however, between avoiding negative distributional impacts and achieving aggregate social gains, since transaction costs, imperfect information and incentive problems may limit the ability to identify and adequately compensate losers.

The impacts of infrastructure development on resource conditions may be very mixed. Where roads or other infrastructure are established near forest areas, they may promote deforestation if open access land exists, farmers are acting as profit maximizers, immigration is relatively easy, and the elasticity of demand for the agricultural products from these areas is high (Angelsen, 1996). On the other hand, if farmers are subsistence oriented, labor is locally constrained, or the elasticity of demand for agricultural production is low, increased production made possible by increased access to roads or irrigation may cause farmers to intensify production on a smaller area of land, thus reducing pressure on forests or marginal lands (Ibid.). The increased value of land caused by infrastructure development will tend to promote labor-intensive investment in land conservation and improvement if land values rise more than wages. It will also tend to promote greater capital intensity, unless improved market access increases people's investment opportunities elsewhere to a greater extent than locally. Knowledge intensity in agriculture is also likely to increase as a result of improved access to markets, information, technical assistance and education. Increases in labor, capital and knowledge intensity and shifts in product mix and occupations brought about by infrastructural development can have both positive and negative impacts on resources and the environment, as discussed earlier.

CHANGES IN COLLECTIVE ACTION

Population growth may cause changes in collective action related to natural resources at the community or other levels. At very low levels of population density, the relative abundance of land and other resources may require little action (whether collective or private) to manage resources. As population grows, increasing scarcity increases the potential rents that can be achieved by protecting and intensively managing land and other resources. At the same time, the costs of organizing may fall as population density grows from low levels, as people begin to live closer together (Templeton and Scherr, 1997).[6] Economies of scale in protecting resources at a collective rather than private level may outweigh incentive problems associated with collective (relative to private) management at low to moderate levels of population density, particularly since management and investment requirements may be fairly limited when intensity of

---

[6] If wages fall as a result of declining labor productivity resulting from population growth, this will also tend to reduce the costs of organizing.

resource use is still relatively low. Thus establishment of common property resources with collective protection and management may become the optimal strategy for managing scarce resources as population density grows to moderate levels.

As population density grows to high levels, the benefits and costs of collective action relative to private action may begin to change. The beneficial effect of increasing population density in reducing organizational costs will decline in importance where people already live in close proximity. At the same time, the need to organize larger numbers of people and the increasing scarcity of resources will make attaining collective action more difficult, since the costs of monitoring and enforcement and the benefits of violating collective restrictions on resource use will be rising. As resource management and investment requirements become greater with increasing use intensity, the incentive problems associated with collective (relative to private) management will increase. Eventually, the net benefits of private management will exceed the benefits of collective management as population grows, promoting a shift in management systems. This shift may occur without a shift to private property--economies of scale in resource protection may favor keeping resources under communal ownership, even though they may be privately managed.

As management decisions become increasingly private in nature, externalities caused by private management decisions of households (e.g., impacts of irrigation or drainage investments by upstream farmers on downstream farmers) may still require some form of collective action, unless transactions costs are sufficiently low that bargaining between rights holders to resolve the externalities is feasible (Coase, 1960). The transactions costs of such an approach may be prohibitive for externalities that affect large numbers of people, and such externalities may proliferate as population density and intensive land management increases. Thus, collective action may evolve from collective protection and management of resources towards regulating or taxing specific types of negative externalities or promoting specific community level investments that generate positive externalities (e.g., community watershed management investments).

The ability to attain collective action in managing resources may depend upon many factors, including the nature of the resource, the nature of the uses of the resource, the nature of the users of the resource, and the existing institutional and organizational strucure within the community (Ostrom, 1990; Rasmussen and Meinzen-Dick, 1995). Collective resource management is more likely to arise and be effective where costs of exclusion are lower but economies of scale in exclusion exist (thus inhibiting privatization); where the benefits of cooperation relative to non-cooperation are greater; where there are fewer users; where the interests of users are more homogeneous;[7] where membership in the users group is less open and more stable; where users are closer to one another physically and socially; where users have longer time horizons; where risks and risk aversion increase the benefits of pooling risks; where norms of cooperation and/or equity exist among users; or where there already exist cooperative organizations upon which efforts to attain collective action can build (Ibid.; Baland and Platteau, 1996).

[7] Note that homogeneity of wealth does not necessarily imply homogeneity of interests, and wealth heterogeneity may favor collective action (Olson, 1965; Baland and Platteau, 1996).

Population growth may promote collective action through its effects on many of these factors. It may reduce the per capita costs of protection of the resource, if there are economies of scale in this. It tends to increase the benefits of cooperation, since it increases the scarcity rents achievable by good management. It may increase the geographic and social proximity of resource users by increasing population density.

On the other hand, population growth also may detract from collective action for many reasons. Since it increases resource rents, it also increases the benefits to be gained by cheating on collective agreements. It increases the number of resource users and perhaps their diversity of interests. It reduces the stability of membership of the users group, particularly if population growth is rapid and/or there is significant immigration or emigration from the community. Related to this, population growth may also undermine group stability and incentives to cooperate to the extent that it promotes infrastructure and market development. To the extent that population growth increases poverty, it may cause people to have higher discount rates and shorter time horizons. Increasing scarcity and rapid population change may erode norms of cooperation and equity, particularly where migration and commercialization are substantial.

As I have argued above, the balance of these factors is expected to weigh in favor of collective action at moderate levels of population density and growth. However, at very high levels of population density or growth, the factors tending to undermine collective action appear likely to dominate. Thus, we may observe an inverted U-shaped relationship between population density or population growth and collective action for resource management.

To the extent that collective action for natural resource management follows from increased demands generated by population growth, it will tend to promote greater welfare and improved resource conditions for the members of the collective, although this may involve some near term sacrifice on the part of individuals for the sake of greater collective gains. However, there may be adverse distributional impacts on weaker members of the collective groups, or on outsiders. For example, collective grazing restrictions may be established that allow farmers to cut and carry fodder grasses to feed draft animals, but limit access of goats and sheep to grazing areas. Such restrictions may benefit the wealthier members of the community at the expense of poorer ones, who may own fewer draft animals and may be more dependent upon small ruminants for their livelihoods. There can also be adverse impacts on resources outside of those collectively managed. For example, establishment of a protected grazing area as mentioned above may increase grazing pressure on unprotected areas. Thus collective action may displace rather than solve resource management and poverty problems, unless the action is sufficiently encompassing of affected groups and resources.

INSTITUTIONAL CHANGE

Closely related to the development of collective action is the prospect of institutional change, particularly regarding changes in property rights and land tenure relations. As population pressure and intensity of land use increase, the demand for more secure rights to specific pieces of land or other resources will increase (Boserup, 1965; Demsetz, 1967; Ault and Rutman, 1979; Binswanger and McIntire, 1987; Platteau, 1996). This demand may be accommodated within customary land tenure systems by allowing households long term use and inheritance rights to specific resources. As relative factor scarcities change, the demand for land and other factor transactions may increase. Land leasing and sharecropping may arise, allowing more efficient use of available factors of production, which may differ across households. Where capital intensification is occurring, increased demand for credit will increase the demand to be able to mortgage land. Customary rights to mortgage or even sell land may evolve (Platteau, 1996). In short, customary land rights may evolve from communal to more private forms. This evolution may proceed without external intervention, although it is often assumed that formal land titling arrangements are necessary for this process to occur (Ibid.).

The demand for other forms of institutional innovation are likely to increase as population grows as well. In addition to land markets, other markets are also likely to arise. Markets for labor are likely to develop as increasing land scarcity causes land poor households to seek employment elsewhere, whether on other farms or in off-farm activities (particularly where land quantity or quality are unevenly distributed). Markets for capital inputs, such as draft animals, farm equipment, and purchased inputs, are also likely to develop as the demand for such inputs develops. The demand for credit services will also increase as the use of capital inputs increases. As labor moves out of agriculture and into other activities, increased trade in food and other agricultural products will be needed, promoting development of product markets. To the extent that population growth promotes investment in transportation infrastructure, this will also help to promote commercialization and market development.

The demand for non-market institutions may also rise as population grows (Hayami and Ruttan, 1985). For example, the demand for regulation of the use of resources is likely to increase as population pressure increases externality costs. The demand for institutions to share the costs of infrastructure investment, which will be declining on a per capita basis as population grows, will also increase. Similarly, the demand for institutions to share the costs of agricultural innovation or internalize some of the positive externalities resulting from innovation will also be growing as population grows.

Many factors condition whether the supply of institutional innovation is consistent with the changing demand (Ibid.). Where political entrepeneurship is needed to bring about institutional change, the factors influencing the private costs, benefits and risks faced by such entrepeneurs are likely to be critical. The relative power of particular interest groups may prevent institutional changes from occurring, even if their potential net social benefits may be very high. For example, a shift from communal to private property rights may be prevented by a village chief, whose power and status would be reduced by losing the ability to allocate land rights. Conversely, “rent seeking” forms of institutional innovation may occur where these serve the interests of powerful groups, despite the fact that they may not promote greater welfare in general. It has been argued that land titling efforts are sometimes of this nature, providing an opportunity for well connected elites to claim land used by weaker or less well informed households (Platteau). Cultural factors may also have a strong impact on the supply of institutional innovation (Hayami and Ruttan). For example, cultures which foster strong norms of cooperation and reciprocity are likely to find it easier than other cultures to develop institutions to share the costs of infrastructural development or innovation. On the other hand, strong egalitarian norms may cause animosity towards complete privatization of property rights, particularly the elimination of common lands available to the poorest people, or the alienation of an individual's right to land through sale or foreclosure on a mortgage (Platteau). Education may also have a strong influence on the receptivity of people to institutional innovation, and on the likelihood that the innovations that come about are efficiency improving (Hayami and Ruttan).

Clearly there is much more to institutional change than a simple response to changes in net social benefits. Much of the challenge in understanding modern economic history is in understanding why institution innovations that promote greater efficiency and economic development are adopted in some circumstances while seemingly inefficient institutions persist over very long periods in others (North, 1990). The role of differential power relations, cultural factors, education, and other location specific conditioning factors may explain a large fraction of the variance in outcomes. But North also pointed to the nature of the process of institutional innovation itself as a source of divergence.

Institutions condition the nature of expectations and the range of permissible activities, and those expectations and activities may reinforce the strength of the institutions. Thus institutional change may be a self-reinforcing process characterized by multiple equilibrium outcomes and path dependency (Ibid.). Even small differences in initial conditions between different societies may lead to large and persistent differences in their pathways of institutional change. Thus, for example, the pressure of population growth may lead to a smooth transition from common property to private property in some circumstances, while in others the pressure may cause a breakdown in the common property system leading towards unregulated open access. Differences in people's initial expectations about the path that development may take and their assurance that others will respect property rights may account for the differential outcomes. The differences in impacts on natural resource conditions and human welfare between these different scenarios may be very extreme.

In general, the impacts of institutional change for welfare and resource conditions will be via its impacts on the conditioning factors affecting all of the previous responses considered. Thus, for example, development of more private and secure property rights will inhibit extensification, favor investments in land improvements, promote use of inputs (to the extent that private land rights promote access to credit) and perhaps facilitate migration and changes in occupations. The expected impacts of all of these changes on human welfare and resource conditions are, as we have seen, diverse. In general, however, to the extent that institutional innovation is responding to changes in net social (as opposed to private) benefits, it will lead to increases in general welfare, although there may be adverse distributional consequences.

ORGANIZATIONAL CHANGE

Also closely related to collective action and institutional change is organizational change, which may also be stimulated by population growth. Following Uphoff (1986), I distinguish organizations, defined as “structures of recognized and accepted roles” from institutions, defined as “complexes of norms and behaviors that persist over time”. One may see the roles established in organizations as largely determined by the nature of institutions and technology, since these will tend to define the set of possible roles that may be served by organizational structures and the costs and returns of alternative structures. However, technological and institutional change may also be affected by organizational change. For example, establishment of farmers’ cooperatives may reduce the costs or increase the benefits of extending new technologies and thus promote greater technical innovation. The presence of cooperatives may also facilitate institutional innovation; for example, they may facilitate collective action needed to establish effective regulation of externalities caused by private farming practices.

Population growth is expected to affect organizational development for most of the same reasons that it may affect collective action and institutional development. Since organizational development requires collective action, the factors affecting collective action are also relevant for organizational development. Factors favoring collective action, such as the homogeneity of interests of the members, the stability of the group, proximity of the members, the ability to exclude outsiders, etc., will also tend to favor organizational development by reducing the costs of such development. The demand for new types of organizations serving different functions will also tend to increase as population grows and new economic roles are required. For example, increased use of capital inputs in agriculture may promote not only new institutions such as mortgageable land and markets for such inputs, but it also requires new organizations such as rural banks and input wholesalers and traders.

As with institutional development, organizational development may be affected by power relations, cultural and other factors, and may be subject to path dependency as well. Also, organizational development may not be socially beneficial even where it benefits the members, since organizations may arise to serve rent-seeking motives rather than efficiency enhancement (Olson, 1982). Thus the impacts of organizational development on welfare and natural resources may be quite diverse. Organizations such as water or pasture users groups may improve the management of common property resources for the benefit of all. On the other hand, such groups may be dominated by powerful elites who use the organization as a way of capturing rents for themselves at the expense of other members or those who may be excluded from the group. As with institutional development, organizational development will improve social welfare to the extent that it responds to efficiency motives, although there may be adverse distributional implications.

SUMMARY

To summarize the hypotheses, I have argued that population growth may stimulate a wide variety of responses at the household and collective level. Many of these responses are strongly conditioned by the nature of technology, infrastructure, institutions and organizations. In the absence of development of these factors, population growth is likely to lead to declining labor productivity and human welfare, as a result of diminishing returns. The expected impacts on resource conditions are more mixed and dependent upon the conditioning factors, with population growth inducing agricultural extensification and deforestation in low population density settings with open access land available, but promoting labor-intensive investments in land improvement at higher population densities where land tenure is secure.

The larger impacts of population growth in the long term may be via its impacts on development of technology, infrastructure, institutions and organizations. As emphasized in the literature on induced innovation, population growth may reduce the per capita costs and increase the benefits of innovations in these different areas, leading to welfare and resource improving changes. However, the supply of such innovations and their impacts may be very dependent upon the distribution of wealth and power, cultural factors, education, and other context specific conditions, and these developments may be subject to a substantial degree of path dependency. Thus, very large differences in the impacts of population growth for agricultural productivity, human welfare, and natural resource conditions may occur in communities and households embarked upon different pathways of development. Much of the challenge of empirical policy research on these issues is to identify the factors that lead to different pathways of institutional and technological change, and policy interventions that may help more productive, welfare-enhancing and resource-improving pathways to evolve.

Given the importance of so many complex and site specific conditioning factors and the possibility of path dependence in responses, the impacts of rural population pressure may be very different in different contexts. I now consider evidence of such impacts in the context of the hillsides of central Honduras.

4. EVIDENCE FROM CENTRAL HONDURAS

Recent research conducted by IFPRI in hillside communities of central Honduras provides evidence on some of the hypotheses discussed above.[8] The central hillsides region of Honduras was defined to include all *municipios* (counties) of the Department of Francisco Morazan except two valley communities and five adjacent hillside *municipios* of the Department of El Paraíso. This region is relatively homogeneous in terms of topography (over 90% hillsides), climate (mainly sub-humid tropical), and soils (generally thin and of poor quality). It includes substantial variation in population density, access to markets, and agricultural practices. Rural population density in the region is generally low, averaging 25 persons/km^2 in 1988, though it ranged from as low

---

[8] This section is based on Pender, Scherr and Duron (1999) and Pender and Scherr (1999).

as 9 to as high as 87 persons/ km^2 in some *municipios*. Many villages in the region lack access to a road, requiring up to a half-day by foot or pack animal to reach the nearest road, while many others are located near to paved highways and close to Tegucigalpa, the capital of Honduras. There are serious problems of resource degradation and poverty in the region.

METHODS

The evidence is based on a survey of 48 villages in the central region of Honduras, selected through a random sample stratified by population density and distance to the dominant market in the region (Tegucigalpa). The survey collected information about changes in agriculture and natural resource management between 1975 and 1996, and about the causes and effects of those changes. The survey included a group questionnaire and participatory mapping of community boundaries and resources, augmented by analysis of available aerial photographs, maps, and village level data from the 1974 and 1988 population censuses.

Econometric analysis was used to identify the factors influencing changes in agriculture and natural resource management, and the impacts of those factors on indicators of changes in outcomes, including agricultural productivity, poverty, and natural resource conditions. The response variables analyzed included (among others) indicators of agricultural extensification (change in forest area between 1975 and 1996), change in fallow use, labor intensification (change in use of burning, use of various soil fertility management practices in 1996), labor-intensive land investments since 1975 (terraces, live barriers, stone walls, tree planting), capital intensification (change in use of oxen, plows, and purchased inputs), change in product mix or occupation (classification of communities by "development pathway", based on information on occupation and product mix),[9] collective action (whether or not the community had invested collectively in improving common lands or controlling runoff), and local organizational development (number of local organizations). The outcome variables analyzed included indicators of land and labor productivity (levels and changes in maize yields and wages), poverty (levels and changes in percentage of households with a dirt floor and percentage of households whose last child died), and natural resource conditions (land use on steep lands and perceived changes in cropland quality, forest quality, water availability and water quality).

The econometric model used was determined by the nature of the dependent variable. In most cases, the dependent variables were measured as ordinal variables, either representing a change between 1975 and 1996 (e.g., whether use of a particular practice had increased, stayed the same, or declined; whether the condition of a particular type of resource had improved, stayed the same, or degraded) or the condition of the

---

[9] Six development pathways were identified based on information on change in occupation and product choice, including 1) expansion of basic grains production, 2) stagnation of basic grains production, 3) adoption and expansion of horticultural production, 4) expansion of coffee production, 5) specialization in forestry, and 6) high and increasing importance of non-farm employment. Basic grains production was important in all of the surveyed communities; communities were distinguished more by the other occupations/product choices. See Pender, Scherr and Duron (1999) for more details on the classification of communities by development pathway.

variable in 1996 (e.g., an ordinal index representing the extent of adoption of particular conservation measures, ranging from 0 (no one uses) to 6 (everyone uses)). Ordered probit analysis was used to analyze the factors affecting such dependent variables. In some cases (e.g., changes in wages and indicators of poverty), the dependent variables were measured as continuous variables, and least squares estimation was used. In one case (collective action) the dependent variable was measured as a binary discrete choice; binary probit analysis was used in this case. In one other case (pathway of development), the dependent variable is a choice among several discrete outcomes, and multinomial logit analysis was used.

The variables used to explain determinants of development pathways included factors affecting agricultural potential (altitude and number of rainfall days), population density, access to markets (distance to the urban market and to the nearest road), and access to technology (presence of a technical assistance program since 1975). The variables used to explain changes in household agricultural practices and changes in outcomes included the development pathways, change in population density, whether road access had improved or stayed the same since 1975, change in the adult literacy rate between 1974 and 1988, and the presence of various types of agricultural programs (technical assistance, credit, agrarian reform, or land titling) since 1975. The specification was similar for the cross sectional analysis of conservation measures and levels of outcomes, except that population density and literacy rate were included as explanatory variables instead of changes in these, and distance to the nearest road and to the urban market were used instead of indicators of change in road access. The determinants of organizational development and collective action were similar, but also included total village population (as a factor affecting demand for collective action), the population growth rate and growth rate squared (to investigate the hypothesis of an inverted U-shaped relationship between population growth and collective action), and the percentage of the village that had been born in the same municipality (to investigate whether stability of village population affects collective action).[10]

Possible endogeneity of some explanatory variables—particularly population growth, the development pathways, and government programs—could lead to biased estimates. In all regressions including these explanatory variables, we ran the regressions twice, using predicted and actual values of these variables, to investigate the robustness of the results.[11] We report which results are significant and robust below. In all regressions, the standard errors were corrected for sample weights, stratification, and finite population, and are robust to heteroskedasticity.

---

[10] See Pender, Scherr and Duron (1999) and Pender and Scherr (1999) for more details on the econometric specifications.

[11] The pathway variables are predicted using the multinomial regression described previously. Population growth and the presence of government programs were predicted using 1974 population density, indicators of agricultural potential (altitude and average number of rainfall days), distance of the village from Tegucigalpa, and indicators of wealth and access to various services in 1974 (proportion of households with a dirt floor, access to potable water, sanitation, electricity, radio, or a sewing machine in 1974; adult literacy rate in 1974). Standard errors were not corrected for the use of predicted values of explanatory variables in these regressions because of the difficulty of deriving analytical formula for the covariance matrix for such complex models (e.g., multinomial logit, probit, and least squares used in the first stage regressions, ordered probit in the second stage). Bootstrapping was also judged not to be appropriate because of the small number of observations per stratum (12). Thus, Pender, Scherr and Duron (1999) did not report the results of the multistage regressions, but only use them to check the robustness of the findings.

RESULTS

Impacts on Responses

The empirical results concerning the impacts of population pressure on household and collective responses in central Honduras are summarized in Table 3. As hypothesized, we find that population growth is significantly and robustly associated with agricultural extensification, as measured by the likelihood of decline in forest area. Population growth is also associated with collective action and organizational development, and the relationship has the hypothesized inverted-U shape. A higher population level is also associated with collective action and organizational development (though the result is robust only for organizational development), consistent with the hypothesis that higher population implies higher demand for such collective responses. As expected, higher population density is associated with some labor-intensive practices and land investments, including use of cattle manure and investments in live barriers and trees. Lower initial population density was positively associated with expansion of basic grains (maize, beans and sorghum) production and expansion of horticultural production (although the result was robust only for horticultural expansion). Higher population density is associated with less likelihood of collective action to improve common lands and control runoff, consistent with the expectation that resource scarcity may undermine collective action.

None of the statistically significant results is inconsistent with our expectations, as noted above. However, the lack of significant impact of population pressure on many responses is also notable, particularly with regard to changes in the fallow system and adoption of several labor-intensive practices and land investments. Reductions in use of fallow and adoption of labor-intensive measures were much more strongly influenced by access to technical assistance and other government programs, and the development pathway being pursued. In general, technical assistance programs promoted more labor-intensive practices, especially conservation practices. Other programs had mixed effects on such practices. Adoption of labor-intensive measures varied greatly across development pathways, with different measures apparently suited to different pathways.

Capital intensity was also not significantly affected by population pressure, and much more affected by road access and the development pathways. Road access favored all kinds of capital intensification. Adoption of purchased inputs was more common in more commercialized pathways, while use of oxen and plowing was less common in the more peri-urban non-farm employment and horticultural pathways.

Although population pressure did not have a statistically significant direct effect on many aspects of intensification in the econometric analysis, this does not prove that population pressure had no impact on these aspects. Given the relatively small number of observations, the statistical power to discern such effects was relatively low, especially

Table 3 Evidence of responses to population pressure in Central Honduras

Response	Indicator	Effect of	Effect
Extensification	Change in forest area (1975-1996)	Change in population density (1974-1988)	- ®
Shorten fallow cycle	Change in use of fallow	Change in population density	0
Labor intensification	Change in use of burning	Change in population density	0
	Use of contour planting (in 1996)	1988 population density	0
	Use of mulching		0
	Use of incorporation of crop residues		0
	Use of cattle manure		+ ®
Labor-intensive land investments	Constructed terraces (since 1975)	1974 population density	0
	Planting live barriers		+ ®
	Constructing stone walls		0
	Planting trees		+ ®
Capital intensification	Change in oxen use	Change in population density	0
	Change in use of plow		0
	Change in use of insecticides		0

Table 3 Evidence of responses to population pressure in Central Honduras (continued)

Response	Indicator	Effect of	Effect
Change in product mix/occupation (development pathway)	Basic grains expansion	1974 population density	-
	Horticultural expansion		- ®
	Coffee expansion		0
	Forestry expansion		0
	Non-farm employment expansion		0
Collective action	Collective investment to control runoff/improve common lands	1974 population	0
		1974 population density	- ®
		Population growth rate (1974-1988)	+ ®
		Population growth rate squared	- ®
Organizational development	Number of local organizations	1974 population	+ ®
		1974 population density	0
		Population growth rate (1974-1988)	+ ®
		Population growth rate squared	-®

+ means a positive and statistically significant effect at the 5% level.

- means a negative and statistically significant effect at the 5% level.

0 means effect is not statistically significant at the 5% level.

® means the effect is also statistically significant at the 10% level if population growth (where applicable), government programs and development pathways are replaced by their predicted values in the regression.

Source: Pender, Scherr and Duron, 1999; Pender and Scherr, 1998 for responses that did not vary greatly within the sample (such as qualitative changes in use of particular practices, which were generally in the same direction, or adoption of conservation measures, which was generally low).

Furthermore, population pressure may have indirect effects on intensification via its effects on other factors, such as the development pathways, government programs, or infrastructure development. For example, since lower initial population density appears to have favored horticultural expansion, and horticultural expansion is associated with adoption of purchased inputs, population pressure may indirectly reduce use of purchased inputs by undermining horticultural expansion. Lower initial population density is also associated with the presence of technical assistance programs and road development, perhaps because people are wealthier and more politically connected in less densely populated areas.[12] Paradoxically, lower population density communities may thus have been encouraged to adopt more labor-intensive methods by technical assistance programs than in higher population density communities where such programs were less present. Lower population density also appears to have favored adoption of capital intensive methods, to the extent that this contributed to road development. These indirect effects do not support the hypothesis of population-induced intensification of labor or capital.

[12] This result is from the regressions used to predict the presence of government programs. Population density did not have a significant effect on the presence of other government programs. These regression results are available upon request.

Impacts on Outcomes

The impacts of population pressure on outcomes in central Honduras are summarized in Table 4. Population density is found to have a negative association with maize yield and with the presence of forest on steep land (having slope greater than 30%), and a positive association with cultivation on steep lands. The negative association of population density and maize yield is not consistent with our expectations of the effects of population-induced labor intensification, and suggests that population pressure is associated with land degradation. This is consistent with the estimated impact of population growth on changes in maize yields and perceived cropland quality, although these impacts were not statistically significant at the 5% level. The associations of population density with forest and cultivated area on steep lands are consistent with the hypothesis of population-induced intensification on marginal lands, and also with the results on forest area discussed earlier. Generally, the evidence suggests that population pressure is causing land degradation in central Honduras.

We do not find evidence of a significant and robust impact of population density or population growth on indicators of labor productivity or poverty. Surprisingly, population growth is positively associated with wage growth, but this effect is not robust when predicted population growth is used in the regression. This suggests that the positive association is due to the endogeneity of population growth, and that population growth responds positively to rising wages (via migration), rather than the other way around.

Table 4 Evidence of outcomes of population pressure in Central Honduras

Outcome	Indicator	Effect of	Effect
Productivity	Maize yield, 1996	Population density, 1988	- ®
	Ln(high male wage), 1996		0
Change in productivity	Change in maize yield, 1975-96	Change in population density, 1974-88	0
	Change in ln(male wage)		+
Resource conditions	Forest on steep land, late 1970's	Population density, 1974	- ®
	Cultivation on steep land, late 1970's		+ ®
Change in resource conditions	Perceived change in cropland quality, 1975-96	Change in population density	0
	Perceived change in forest quality		0
	Perceived change in water availability		+
	Perceived change in water quality		+
Poverty	Proportion of houses with a dirt floor, 1988	Population density, 1988	0
	Proportion of households where last child died		0
Change in poverty	Change in proportion of houses with a dirt floor, 1974-1988	Change in population density, 1974-1988	0
	Change in proportion of households where last child died		0

+ means a positive and statistically significant effect at the 5% level.
- means a negative and statistically significant effect at the 5% level.
0 means effect is not statistically significant at the 5% level.
® means the effect is also statistically significant at the 10% level if population growth (where applicable), government programs and development pathways are replaced by their predicted values in the regression.

Source: Pender, Scherr and Duron, 1999

As discussed above, the insignificant impacts of population pressure in these regressions do not prove that it has no effect. The statistical power of the regressions is low, as noted above. Furthermore, the impacts of population growth may be dispersed by migration. For example, changes in wages and poverty may be similar across communities as a result of migration, even though population growth may be having a generalized impact on wages and poverty in the central region of Honduras as a whole. It is difficult to identify such effects in a study conducted in a single, relatively integrated labor market.

To the extent that population pressure affected the development pathways (and other factors), it may have had indirect effects on outcomes. Table 5 presents the results of simulations of the direct and indirect effects of changing population density and road access on various outcomes, assuming the indirect effects are due to the effects on development pathways.[13]

The indirect impacts of population pressure are smaller in magnitude than the direct effects in all cases, and in the same direction as the direct effects in all but one case (effect on maize yield). The predicted overall effects of population pressure are unfavorable for land productivity and pressure on steep lands, favorable for wages and

---

[13] I do not estimate the indirect effects of population pressure on outcomes via its impact on presence of government programs, because of the insignificance (and sometimes implausible signs) of the coefficients of government programs in the outcome regressions. I do not estimate the predicted effects of population growth on measures of changes in outcomes because most of these measures are ordinal variables (except changes in poverty measures), making the interpretation of predicted values problematic.

Table 5 Predicted effects of population pressure and market access on outcomes

Factor	Effect	Productivity, 1996		Resource conditions, late 1970s			Poverty, 1988	
		Maize yield	ln (male wage)	Percentage of steep land in forest	Percentage of steep land de-vegetated	Percentage of steep land cultivated	Percentage of houses with dirt floors	Percentage of households where last child died
		(kg/ha)	*(Lps/day)*					
Higher population density (by 1	Direct	-31.3	0.0037	-0.55	0.32	0.25	-0.22	0.02
	Indirect	6.6	0.0028	-0.37	0.29	0.03	-0.09	0.00
	Total	-24.7	0.0065	-0.92	0.61	0.28	-0.31	0.02
Further from road (by 1 km)	Direct	-119.4	-0.0615	-0.91	2.64	-1.17	-0.51	0.24
	Indirect	-366.2	-0.0930	2.52	-4.14	1.22	1.01	0.35
	Total	-485.6	-0.1545	1.61	-1.50	0.05	0.50	0.59

Source: Pender, Scherr and Duron (1999).

housing quality, and negligible for child mortality. In general the predicted impacts are relatively small, particularly in comparison to the impacts of road access. If improvements in road access were undermined by population pressure (recall the negative association between initial population density and road construction noted above), population pressure may have had additional indirect impacts which would have helped to reduce deforestation on steep land but also reduced productivity and increased poverty.

CONCLUSIONS

There are many possible household and collective responses to rural population pressure. These responses are affected by many site-specific factors, may interact in complex ways, and may be subject to path dependency. It is therefore difficult to predict what impacts rural population pressure will have on agriculture and natural resource management, agricultural productivity, poverty or natural resource conditions. I have considered a large number of plausible hypotheses about these impacts, arguing that the impacts of population growth are more likely negative when there is no collective response than when population growth induces infrastructure development, collective action, institutional or organizational development. Beyond this general proposition, the impacts of population pressure, particularly on natural resource conditions, may be very different in different contexts. Thus careful empirical work is required in different contexts before general conclusions can be drawn.

Despite the large volume of literature and debate concerning the relationship between population pressure and resource conditions in developing countries, there is still a paucity of empirical evidence from which to draw general conclusions. Much of the evidence that is cited is based on case studies that, though useful, may not be generalizable. In this chapter, I have reported results from two recent studies of these issues in central Honduras, based on a survey conducted in a representative sample of villages. Conducting similar studies in different agroecological and socioeconomic environments would help to overcome the present gap in empirical knowledge about the impacts of rural population growth on natural resource management and their implications.

The results from Honduras support the concern that population pressure leads to land degradation in a situation of relatively low population density and available land, by encouraging expansion of agricultural production onto marginal steep lands and causing lower land productivity. We also found that population pressure promoted adoption of some labor-intensive soil fertility management practices and land improvements, although the adoption of such practices remained low and was largely determined by the presence of technical assistance programs. Moderate population growth was found to promote collective action to manage common resources and organizational development, consistent with the induced innovation hypothesis. Despite these impacts, we found that population pressure had a statistically insignificant impact on wages and poverty, and that the magnitude of the estimated impacts were relatively small. Even when indirect impacts of population pressure on occupational and product choice were considered, the impacts remained relatively small.

The results from central Honduras suggest that other factors besides population pressure have been more important in determining agricultural change, resource management practices, wages and poverty. Notable among these are road development and technical assistance programs. Although induced innovation theory suggests that both of these types of interventions would be more likely in more densely populated settings, we found just the opposite—i.e., these interventions were more likely in less densely populated communities. This may have been an anomalous result of the particular political setting of Honduras. Nevertheless, it emphasizes the point that such “induced” policy responses are by no means automatic, nor necessarily in the direction one might expect. It also suggests that policies may not have been efficient; for example, by promoting labor-intensive practices through technical assistance programs focused in less densely populated areas.

The evidence from central Honduras suggests the importance of considering the complex array of conditioning factors that influence the responses of communities and households to population growth or other pressures. Particularly important among these are the factors leading to differences in changing comparative advantage, as summarized by the pathways of development. Within particular development pathways, the processes of induced technological, institutional and organizational development may proceed differently, with different long term implications for resource management and human welfare.

The results from Honduras may not be representative of situations where initial population density, agricultural potential or other factors are significantly different. In particular, the relatively low population density of central Honduras may account for the limited degree of intensification and innovation found in response to population pressure. It may be that such responses only occur at higher population densities than were present in most of the study communities. Further research is needed to explore these issues in different demographic, agroecological and socioeconomic contexts.

6. ACKNOWLEDGMENTS

The author gratefully acknowledges the financial support of the Swiss Development Cooperation and the Inter-American Development Bank for this research, and institutional support from the International Food Policy Research Institute and the Inter-American Institute for Cooperation in Agriculture. I am grateful to my colleague, Sara Scherr and to the Honduras study team—Guadalupe Duron, Fernando Mendoza, Carlos Duarte, Juan Manuel Medina, Oscar Neidecker-Gonzales, and Roduel Rodriguez—for their valuable contributions to the Honduras field work for this study. I am also grateful to Allen Kelley, Nancy Birdsall, Jere Behrman, and other participants in the Symposium on Population Change and Economic Development cosponsored by the Rockefeller Foundation, the Packard Foundation and the United Nations Population Fund and held in Bellagio, Italy in November 1998, for valuable comments on this paper, which was presented at the symposium. This paper is being published as a chapter of a book based upon that conference. I am especially grateful to the many farmers and others in Honduras who generously agreed to respond to our many questions.

REFERENCES

Angelsen, A. 1999. Agricultural expansion and deforestation: modelling the impact of population, market forces and property rights. *Journal of Development Economics* 58: 185-218.

Angelsen, A. and D. Kaimowitz. 1998. *When does technological change in agriculture promote deforestation?* Paper presented at the AAEA International Conference on Agricultural Intensification, Economic Development, and the Environment, Salt Lake City, July 31-August 1, 1998.

Arrow, K.J. 1962. The economic implications of learning by doing. *Review of Economic Studies* 29 (June): 155-173.

Ault, D.E. and G.L. Rutman. 1979. The development of individual rights to property in tribal Africa. *Journal of Law and Economics* 22(1): 163-182.

Baland, J-M., and J-P. Platteau. 1996. *Halting degradation of natural resources. Is there a role for rural communities*. Oxford: Clarendon Press.

Becker, G. and H. Lewis. 1973. On the interaction between the quantity and quality of children. *Journal of Political Economy* 81(2), pt. 2.

Besley, T. 1995. Property rights and investment incentives: Theory and evidence from Ghana. *Journal of Political Economy* 103(5): 903-937.

Bilsborrow, R.E. and D.L. Carr. 1998. *Population, agricultural land use and the environment in developing countries*. Paper presented at the AAEA International Conference on Agricultural Intensification, Economic Development, and the Environment, Salt Lake City, July 31-August 1, 1998.

Binswanger, H.P., and J. McIntire. 1987. Behavior and material determinants of production relations in land abundant tropical agriculture. *Economic Development and Cultural Change* 36(1):73-99.

Blaikie, P. and H. Brookfield, eds. 1987. *Land degradation and society.* London and New York: Methuen.

Boserup, E. 1965. *The conditions of agricultural growth*. New York: Aldine Publishing Co.

________. 1981. *Population and technological change: A study of long-term change.* Chicago: University of Chicago Press.

Buresh, R., P.A. Sanchez, and F. Calhoun, eds. 1997. *Replenishing soil fertility in Africa*. SSSA Special Publication No. 5. Madison: Soil Science Society of America.

Clay, D., T. Reardon and J. Kangasniemi. 1998. Sustainable intensification in the highland tropics: Rwandan farmers investments in land conservation and soil fertility. *Economic Development and Cultural Change* 46:351-377.

Coase, R. 1960. The problem of social cost. *Journal of Law and Economics* 3(October): 1-44.

Demsetz, H. 1967. Towards a theory of property rights. *American Economic Review, Papers and Proceedings.* 57(2): 347-359.

Easterlin, R.A., ed. 1980. *Population and economic change in developing countries*. National Bureau of Economic Research. Chicago: University of Chicago Press.

Ehrlich, P.R. and A.H. Ehrlich. 1990. *The population explosion.* New York: Simon and Schuster.

Feder, G., T. Onchan, Y. Chalamwong, and C. Hongladaron. 1988. *Land policies and farm productivity in Thailand.* Baltimore: The Johns Hopkins University Press.

Goldman, A. 1995. Threats to sustainability in African agriculture: Searching for appropriate paradigms. *Human Ecology* 23(3): 291-334.

Harris, J.R. and M.P. Todaro. 1970. Migration, unemployment and development: A two-sector analysis. *American Economic Review* 60 (March): 126-142.

Hayami, Y, and V.W. Ruttan. 1985. *Agricultural development: An international perspective*, 2nd edition. Baltimore: Johns Hopkins University Press.

Herweg, K. 1993. Problems of acceptance and adoption of soil conservation in Ethiopia. *Topics in Applied Resource Management* 3: 391-411.

Holden, S., B. Shiferaw and M. Wik. 1998. Poverty, credit constraints, and time preferences: Of relevance for environmental policy? *Environment and Development Economics* 3:105-130.

Kates, R. and V. Haarmann. 1992. Where the poor live: Are the assumptions correct? *Environment* 34(May): 4-28.

Krautkraemer, J.A. 1994. Population growth, soil fertility, and agricultural intensification. *Journal of Development Economics* 44: 403-428.

LaFrance, J.T. 1992. Do increased commodity prices lead to more or less soil degradation? *Australian Journal of Agricultural Economics* 36(1):57-82

Lele, U. and S.W. Stone. 1989. *Population pressure, the environment and agricultural intensification in sub-Saharan Africa: Variations on the Boserup hypothesis*. MADIA Discussion Paper No. 4. Washington, D.C.: World Bank.

Lewis, W.A. 1954. Economic development with unlimited supplies of labor. *The Manchester School* 22 (May): 139-191.

Lipton, M. 1977. *Why poor people stay poor: Urban bias in world development*. Cambridge: Harvard University Press.

Lopez, R. 1998. *Where development can or cannot go: The role of poverty-environment linkages.* Annual World Bank Conference on Development Economics 1997. Washington, D.C.: World Bank.

Lucas, R.E. 1988. On the mechanics of economic development. *Journal of Monetary Economics* 22:3-42.

McIntire, J., D. Bourzat, and P. Pingali. 1992. *Crop-livestock interactions in sub-Saharan Africa*. Washington, D.C.: World Bank.

North, D.C. 1990. *Institutions, institutional change and economic performance*. Cambridge: Cambridge University Press.

Olson, M. 1965. *The logic of collective action. Public goods and the theory of groups.* Cambridge, MA: Harvard University Press.

________. 1982. *The rise and decline of nations.* New Haven:Yale University Press.

Ostrom, E. 1990. *Governing the commons: The evolution of institutions for collective action*. Cambridge: Cambridge University Press.

Otsuka, K. 1998. *Land tenure and the management of land and trees in Asia and Africa*. Paper presented at an International Food Policy Research Institute Policy Seminar, Sept. 3, 1998, Washington, D.C.

Pagiola, S. 1996. Price policy and returns to soil conservation in semi-arid Kenya. *Environmental and Resource Economics* 8:251-271.

Panayotou, T. 1994. Population, environment, and development nexus. In *Population and development: Old debates, new conclusions,* R. Cassen, ed. Washington, D.C.: Overseas Development Council.

Pender, J. 1996. Discount rates and credit markets: Theory and evidence from rural India. *Journal of Development Economics* 50(2): 257-296.

________. 1998. Population growth, agricultural intensification, induced innovation and natural resource sustainability: An application of neoclassical growth theory. *Agricultural Economics* 19: 99-112.

Pender, J. and J. Kerr. 1998. Determinants of farmers' indigenous soil and water conservation investments in India's semi-arid tropics. *Agricultural Economics* 19: 113-125.

Pender, J. and J. Kerr. 1999. *The effects of land sales restrictions: Evidence from south India*. Washington, D.C.: International Food Policy Research Institute, Mimeo.

Pender, J., F. Place, and S. Ehui. 1999. *Strategies for sustainable agricultural development in the East African highlands*. Environment and Production Technology Division Discussion Paper 41. Washington, D.C.: International Food Policy Research Institute.

Pender, J. and S.J. Scherr. 1999. *Organizational development and natural resource management: Evidence from central Honduras*. Washington, D.C.: International Food Policy Research Institute, Mimeo.

Pender, J., S.J. Scherr, and G. Durón. 1999. *Pathways of development in the hillsides of Honduras: Causes and implications for agricultural production, poverty, and sustainable resource use*. Environment and Production Technology Division Discussion Paper 45. Washington, D.C.: International Food Policy Research Institute.

Pingali, P., Y. Bigot, and H.P. Binswanger. 1987. *Agricultural mechanization and the evolution of farming systems in sub-Saharan Africa*. Baltimore: Johns Hopkins University Press.

Platteau, J.P. 1996. The evolutionary theory of land rights as applied to sub-Saharan Africa: A critical assessment. *Development and Change* 27:29-86.

Rasmussen, L.N. and R. Meinzen-Dick. 1995. *Local organizations for natural resource management: Lessons from theoretical and empirical literature*. Environment and Production Technology Division Discussion Paper 11. Washington, D.C.: International Food Policy Research Institute,

Reardon, T., E. Crawford and V. Kelly. 1994. Links between nonfarm income and farm investment in African households: Adding the capital market perspective. *American Journal of Agricultural Economics,* 76:1172-1176.

Richards, P. 1985. *Indigenous agricultural revolution: Ecology and food production in West Africa.* Boulder: Westview Press.

Robinson, W.C. and W. Schutjer. 1984. Agricultural development and demographic change: A generalization of the Boserup model. *Economic Development and Cultural Change* 32(2): 355-366.

Romer, P.M. 1990. Endogenous technological change. *Journal of Political Economy* 98: S71-S102.

Ruthenberg, H. 1980. *Farming systems in the tropics, 3rd ed.* Oxford: Clarendon Press.

Salehi-Isfahani, D. 1988. Technology and references in the Boserup model of agricultural growth. *Journal of Development Economics* 28(2): 175-191.

Sanchez, P.A., K.D. Shepherd, M.J. Soule, F.M. Place, R.J. Buresh, A-M. Izac, A.U. Mokwunye, F.R. Kwesiga, C.G. Ndiritu, and P.L. Woomer. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. In

Replenishing soil fertility in Africa, Buresh, R., P.A. Sanchez, and F. Calhoun, eds. SSSA Special Publication No. 5. Madison: Soil Science Society of America.

Scherr, S. J., and P. Hazell. 1994. *Sustainable agricultural development strategies in fragile lands.* EPTD Discussion Paper No. 1. Washington, D.C.: International Food Policy Research Institute.

Schultz, T.P. 1981. *Economics of population*. Reading: Addison-Wesley Publishing Co.

Smaling, E.M.A., ed. 1998. Nutrient balances as indicators of productivity and sustainability in sub-Saharan African agriculture. *Agricultural Ecosystems & Environment*, Special Issue, Volume 71, Nos. 1,2,3.

Solow, R.M. 1956. A contribution to the theory of economic growth. *Quarterly Journal of Economics* 70: 65-94.

Templeton, S., and S. J. Scherr. 1997. *Population pressure and the microeconomy of land management in hills and mountains of developing countries*. EPTD Discussion Paper No. 26. Environment and Production Technology Division. Washington, D.C.: International Food Policy Research Institute.

Tiffen, M., M. Mortimore, and F. Gichuki. 1994. *More people, less erosion: Environmental recovery in Kenya*. Chichester: John Wiley and Sons.

Udry, C. 1996. Gender, agricultural productivity and the theory of the household. *Journal of Political Economy* 104(5): 1010-1046.

Uphoff, N. 1986. *Local institutional development: An analytical sourcebook with cases.* West Hartford: Kumarian Press.

Vasey, D.E. 1979. Population and agricultural intensity in the humid tropics. *Human Ecology* 7(3): 269-281.

Vosti, S.A., J. Witcover, and M. Lipton. 1994. *The impact of technical change in agriculture on human fertility: District-level evidence from India*. Environment and Production Technology Division Discussion Paper 5. Washington, D.C.: International Food Policy Research Institute,

World Commission on Environment and Development. 1987. *Our common* future. Oxford: Oxford University Press.