Induced Innovation

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The process by which societies develop technologies that facilitate the substitution of relatively abundant factors (hence cheap) of production for relatively scarce (hence expensive) factors in the economy is known as induced innovation. The choice between land saving versus labor saving technological change has been largely determined by the relative scarcity of land and labor in a particular society (Hayami and Ruttan, 1985). Population pressure has played a defining role in technology development and farmer choice of technologies. Ester Boserup (1965) argued that societies across the world have responded to increasing land scarcity in a strikingly similar and predictable manner, by increasing land productivity through agricultural intensification. The transition from low-yield, land-extensive cultivation systems to land intensive, double and triple crop systems has only been profitable in societies where the supply of uncultivated land has been exhausted (Boserup 1965; Hayami and Ruttan 1985; Pingali, et. al, 1987). The process of agricultural intensification has been observed in traditional as well as modern agricultural societies. The movement from forest and bush fallow systems of cultivation to annual and multi-crop cultivation systems, whereby plots of land are cultivated one or more times per year, has generally been influenced by rising population densities in traditional societies (Boserup, 1965). It is no accident that the modern seed-fertilizer revolution has been most successful in densely populated areas of the world, where traditional mechanisms for enhancing yields per unit area have been exhausted.

Kikuchi and Hayami (1978) document the process of land augmentation as the cultivation frontier closes for Japan, Taiwan, Korea and the Philippines. "As population pressure pushes the cultivation frontier into marginal areas, we expect the marginal cost of agricultural production via expansion of cultivated area to rise relative to the marginal cost of production via intensification. Eventually the economy will reach a stage at which internal land augmentation becomes a less costly means of increasing agricultural output than external land augmentation," (Hayami and Ruttan, 1985, p 310).

In addition to high population densities, intensive cultivation will also be observed in areas with better access to markets, provided soil conditions are suitable. Intensification occurs in the less densely populated areas for two reasons: 1) higher prices and elastic demand for output imply that the marginal utility of effort increases, hence farmers in the region will begin cultivating larger areas; and 2) higher returns to labor encourage migration into well connected areas from neighboring regions with higher transport costs. In other words, where population densities are low, the returns to intensification are high only if markets, domestic and/or export, are easily accessible, such as the Central Plains of Thailand or parts of South America's Southern Cone. If these conditions are not present, labor and other costs associated with intensive agriculture are substantially higher than its incremental economic returns.

Farmer induced technological change in traditional farming systems

Pingali, et. al (1987) documented, in the case of Africa, the movement from shifting cultivation to permanent agriculture with increases in population densities and improvements in market infrastructure. As land became scarce, traditional farming communities across Sub-Saharan Africa extracted higher and higher levels of output from their land through investments in land improvements and soil fertility management. Erosion control, irrigation and drainage are the most commonly made land investments for enhancing productivity. Tiffen, et. al (1994) provide an excellent case study from Machakos District of Kenya on the process of intensification and farmer investment in land improvements.

The extent of intensification is conditional on the relative responsiveness of the soils to inputs associated with intensive production such as land improvements, manure and fertilizers. As population densities rise, one observes the cultivation of land that requires substantially higher labor input but that is also more responsive to the extra inputs. The responsiveness to intensification is generally higher on soils with higher water and nutrient holding capacity these are usually the heavier, clayey soils, rather than the lighter sandy soils (Pingali, et. al, 1987). The movement from communal access, to individual property rights, with population growth induced increases in land values, provide individuals the incentive to invest in land improvements and other technologies necessary for intensive agricultural systems (Binswanger and Deininger, 1997). Formal land ownership as characterized by the possession of a title also helps the farmer in acquiring credit for making the necessary investments in land and technology (Pingali, 1990).

In using population densities as a basis for predicting the level of agricultural intensification, one ought to standardize arable land by soil quality and climate. Binswanger and Pingali (1988) provide a standardized population density measure: the number of people per million kilocalories of production potential. This measure is called the agro-climatic population density. When countries are ranked by agro-climatic population densities, Niger and Kenya turn out to be more densely populated than Bangladesh, and India ranks only twenty-ninth rather than seventh as in the traditional population rankings. This explains why one observes intensive cultivation in some sparsely populated countries with poor market infrastructure—Niger and Botswana are examples.

Adoption of modern scientific innovations

The intensification of traditional farming systems was a process that the more densely populated regions of Asia had been through several decades, and in some cases centuries, earlier. The application of modern scientific innovations in the form of high yielding seeds and fertilizer allowed the extremely land scarce regions of Asia achieve levels of land productivity that were not possible through the exclusive reliance on traditional farmer innovation systems.

A cross-sectional comparison across Asian countries shows that the proportion of irrigated area and the percentage of area under HYVs and fertilizer use is positively related to population densities (Pingali, et. al, 1997). It was not a historical accident that research for enhancing the yields of the two major foodcrops of Asia, rice and wheat, began in the 1950s. Research investments for enhancing yields were made in response to declining opportunities for area expansion, which was the main source of output growth in the pre-Green Revolution Asia. A comparison of sources of rice output growth during the early and late Green Revolution periods shows that the overall rate of growth was similar for the two time periods. In the early period, one-third of the growth came from an increase in cropped land, while in the latter period almost all of it was due to yield increases. The adoption of the Green Revolution technologies has been spotty in other parts of the world, this reflects in part the differences in land and labor endowments relative to Asia (Pingali and Heisey, 1999). Research on induced intensification has not been restricted to the agricultural economics literature alone, a substantial number of comparative studies that look at the process of intensification, over time and over space, can be found in the geography-anthropology literature, see for example Turner and Brush, 1987 and Turner and Ali, 1996.

Labor use and employment and labor saving technologies

In both traditional and modern agricultural systems, intensification of agriculture leads to an increase in labor use per hectare, due to an increase in the number of tasks performed, such as irrigation, drainage, etc., and due to an increase in the intensity with which some tasks have to be performed, such as more intensive manure use and weeding (Pingali, et. al, 1987). Intensification therefore leads to an increase in agricultural employment as well as an increase in yields per hectare. Labor productivity can only be sustained, as intensity rises, if labor saving technologies are available.

Pingali, et.al, (1997) have argued that the adoption of the plow in African agriculture has been closely associated with the level of intensification. Similarly, increases in labor productivity in Asia are associated with the increasing adoption of labor saving technologies, both as a means of saving on the higher labor needs due to intensification as well as a means of economizing on labor as its opportunity cost rises with economic growth. The movement from single crop cultivation systems to a double- and triple-crop systems shifts out the demand for labor and also increases the demand for timely completion of operations. Initially, the switch to modern varieties was profitable, even with higher labor requirements per hectare, because the labor requirements per ton of paddy were lower compared to that of traditional varieties (Barker and Cordova, 1978). Over time however, increasing labor demand for peak period operations led to a rise in real wages for these operations, even in densely-populated labor surplus countries such as

India and Indonesia. The rise in wages was further exacerbated by the concurrent growth in the rural non-farm sector and increasing employment opportunities in the urban sector, as has happened in Japan and Korea and now being witnessed in Southeast Asia.

Widespread adoption of labor-saving mechanical and chemical technologies has alleviated the growing labor constraints, and contributed substantially to overall productivity growth (Sidhu and Byerlee, 1992). The most notable confirmation of this hypothesis comes from the now developed country, Japan, where graphs plotting the log of land productivity against the log of labor productivity show almost no increases in land productivity but substantial gains in labor productivity in the last thirty years (Hayami and Ruttan, 1985; Craig, Pardey and Roseboom, 1997).

Intensification and degradation – when does the system break down?

The process of population induced technological change is by no means automatic, there are several instances where societies faced with growing population pressure have not been able to achieve sustainable intensification. Failures in agricultural intensification can be attributed to one or more of the following reasons: persistence of uncertain long-term rights to land; encroachment of cultivation onto marginal lands; collective effort required for watershed-level protective investments; and an inappropriate policy environment.

Farmer incentives for regenerating soil fertility and for making erosion-prevention investments are high if secure long-term land rights exist, both to currently cultivated land and to fallow land. Where farmers do not have long-term rights to land, the private rate of discount is higher than the social rate of discount, hence private investments in land productivity will be lower than the societal optimum. In societies with slowly and steadily growing populations, property rights to land evolved systematically, being induced by growing land scarcity. However, the evolution to secure land rights has not been successful in societies experiencing rapid population growth (through natural increase or through migration), nor in societies where this induced institutional change is circumvented by government policies (e.g., land expropriation by colonial authorities or socialist governments).

Given secure rights to land, the rate of return to land investments varies by agroclimatic zone and soil type: degradation problems are most severe where the returns to land investments are lowest. The arid fringe areas, upper slopes in the semi-arid and the humid zones, and shallow sandy soils exhibit the highest levels of erosion, other things being equal. Degradation problems are likely to be most severe in regions with relatively large endowments of marginal lands.

Degradation of marginal lands is also likely to be severe where institutional arrangements are not available for controlling access to grazing and forestry. Where privatization is infeasible or undesirable, community action or government intervention is required both for control of access and for investments in erosion control and forest replanting. Difficult dilemmas frequently arise as traditional users are threatened with a loss of their use rights. Societies are often incapable of solving these problems of ownership or controlled access before serious damage has occurred.

In several instances, inappropriate policies, both micro and macroeconomic, have created disincentives for farmer investments in land productivity enhancing and/or resource conserving technologies (Binswanger, 1996). Pingali et. al., (1997) argue that even in the intensive lowland cereal production systems, where Green revolution technologies were most successfully adopted, price and trade policy distortions are leading to significant levels of environmental and ecological degradation.

The potential problems of declining labor productivity and environmental degradation are not problems of levels of population densities. Given sufficient time, it is likely that a combination of farmer innovations, savings, and the development of research facilities and institutions for dealing with soil degradation issues will be able to accommodate much more than the current population in most countries, especially in many of the less densely populated ones. However, if all these changes are required quickly and simultaneously because of high population growth rates, they may emerge at too slow a pace to prevent a decline in human welfare.

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