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Understanding the Process of Agricultural Adaptation to Climate Change: Analysis of Climate-Induced Innovation in Rice Based Cropping System of Nepal

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Understanding the Process of Agricultural Adaptation to Climate Change: Analysis of Climate-Induced Innovation in Rice Based Cropping System of Nepal

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Abstract

Using Nepal's district level time-series data (1991/92 and 2002/03), this research examines the extent to which technological innovations have provided farmers with options to substitute for climatic constraints in order to enhance rice productivity in climatically diverse regions of the country. The findings from both empirical and qualitative assessments indicate that Nepal's research establishment is engaged in and committed to the development of location-specific technologies that address the constraints of climate. The outcome of such commitment has been a series of technological innovations and changes in policies in agriculture. Together, this may have been responsible for higher yields among districts with marginal climate, which have subsequently led to convergence of the rice productivity growth rate in the country. If the current trend in limiting the deleterious effects of climate in agriculture through appropriate technological as well as institutional changes continues then the prospect of adapting to future climate is more plausible in Nepal.

Key words: climate-induced innovation, Nepal, rice productivity, technological change

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About the Author

Netra is currently a Postdoctoral Research Associate at the Consortium for Science, Policy and Outcomes at Arizona State University. His work seeks to understand science policy interface to support climate-related decision making in the face of fundamental uncertainties. Other areas of Netra's academic research include sensitivity analysis of ecosystems to climate change; risks and vulnerability assessment; land-use land cover change; political ecology of land degradation; community based resource management; and sustainable agriculture. He recently completed his PhD in geography with a minor in demography from Penn State University. Prior to pursuing his academic degree, Netra worked in community development and natural resource management in Nepal. In the Third Assessment Report (TAR) of the Working Group II of the Intergovernmental Panel on Climate Change (IPCC), Netra was involved in the review and synthesis of literature for Chapter 5 "Ecosystems and Their Goods and Services." In the upcoming Fourth Assessment report of the IPCC, Netra is a contributing author on Chapter 5 "Food, Fibre, and Forest Products."

Understanding the Process of Agricultural Adaptation to Climate Change: Analysis of Climate-Induced Innovation in Rice Based Cropping System of Nepal

Netra B. Chhetri

1. INTRODUCTION

One of the challenges in estimating the potential consequences of climate change on agricultural production anywhere in the world is understanding how farmers adapt. Using Nepal's district level time-series data for the period between 1991/92 and 2002/03, this research examine the extent to which technological innovations have provided farmers with options to substitute for climate in order to enhance rice (*Oryza sativa* L) productivity in climatically diverse regions of the country. Drawing upon the hypothesis of induced innovation, which states that the direction of technological innovation in agriculture is induced by difference in relative resource endowments, the goal in this research is to investigate whether variations (spatial and temporal) in climatic resources prompted the development of location-specific technologies that substituted for climatic limitations in the rice-based cropping system of Nepal.

The justification for this research is built on the premise that in order to know how well farmers and their supporting institutions might be prepared to adapt with the change in climate (the characteristic of which remains relatively unknown), it is important to understand how well society has adapted to variability in climate in the past, and consequently to minimize the risks associated with it. Exploring the ways in which technological innovations have provided farmers with the means to respond to climatic limits can offer insights about the adaptation of Nepal's rice based cropping systems to future climate change.

In the next sections I review the salient literature that supports the central argument of this research followed by the theoretical framework of this research. Since management of climatic risks is a critical aspect of maintaining rice productivity in Nepal a discussion of the role of climate in innovation of location-specific technologies is discussed in section four. Section five and six set the stage for this research through providing biophysical context of Nepal, rice farming in the country, and briefly the research and development setting within which the process of technological innovation occurs. In section eight, a discussion on the unit of analysis, data and variable, and sources of data are presented. The rationale for the inclusion of specific variable within the context of this research is also discussed. In section nine I will discuss the methodological approach devised to investigate climate technology interaction in rice farming system of Nepal followed by the presentation of the results. A discussion of the results in light of the existing research and development efforts of the country will be provided in section ten. While drawing conclusion this paper sheds light about the prospect of agricultural adaptation to climate change.

2. BACKGROUND

While the extent of impacts of climate change on agriculture is affected partly by the nature of climate change, it is also dependent on the ability of society to innovate technologies to substitute for climate (Glantz, 1991). Case studies on technological substitutions in response to climatic limitations include innovation of crop cultivars with the optimum physiology for local climatic conditions, development of location-specific agronomic practices, and translocation of crops across different climatic gradients in response to changing climatic conditions. For example, to escape the effects of drought, scientists in the African Sahel have developed cowpea cultivars with varying phenological characteristics and maturity level. Cowpeas cultivars such as *Ein El Gazal* and *Melakh*, matures between 55 – 64 days after planting, and can easily escape the effects of late season drought (Elawad and Hall, 2002). Similarly, scientists have also developed a cowpea cultivar (*Mouride*) that begins flowering in about 38 days after planting and spreads over an extended period of time, thereby avoiding a mid-season drought (Cisse et al., 1997; Hall, 2004).

Technological innovation made in response to the climatic condition of Ontario, Canada resulted in significant growth in area under soybean cultivation from 1970-1997. A fundamental climatic constraint to soybean cultivation in Ontario was the prevalence of cold night temperature during flowering, thereby confining soybean cultivation to the extreme southwestern portion of the province. A key innovation to address this constraint was the introduction of cold-tolerant genetic material (*Fiskeby63*) from Sweden that led to the development of *Maple Arrow* cultivar which eventually played a vital role in the eastward spread of soybean crop. Technological innovations were not only confined to the development of cultivars alone, a range of agronomic activities including modification of planting time and crop rotation interrupted pest cycle all enhanced the cultivation of soybean (Smithers and Blay-Palmer, 2001). Likewise, in response to increase in frost-free growing season since the middle of 20th century, farmers in Australia have changed planting dates and adopted the variety that can take the advantage of longer growing season (Howden, et al., 2002). In another example, farmers in the semiarid tropics of Kenya and Ethiopia have been able to increase efficiency of water use through a combination of water harvesting techniques and drip irrigation that has enabled them to diversify cropping systems and minimize risk from increasing drought spells and erratic rainfall pattern (Ngigi et al., 2000).

Yet, notwithstanding this recognition, there is a dearth of research that investigates the role of climate as a stimulus for innovation of appropriate technologies (Ausubel, 1995; Ruttan, 1996; NRC, 1999). It is in this premise that this study seeks to investigate whether climatic limitations have been factored into the research and development of agricultural technologies. Insights from this research will provide informed policy and pragmatic choices about possible adaptation strategies that farmers and their supporting institutions in Nepal need to adopt in order to ensure food security in the face of deleterious climate change.

3. THEORETICAL FRAMEWORK

Agricultural adaptation to climate change can be viewed as a dynamic process of adjustment in technologies, the understanding of which requires some concept of the driving forces of the changes in them. The hypothesis of induced innovation, articulated by Hayami and Ruttan in the early 1970s, is such a concept and has earned wide recognition as a predominant economic theory of agricultural development. The most fundamental insight of this hypothesis is that investment in innovation of new technology is the function of change (or difference) in resource endowment and the price of the resources that enters into the agricultural production function. This has spawned a conceptual infrastructure that addresses the broader issues of how farmers and public institutions determine priorities for agricultural production (Kappol, 1995).

The hypothesis of induced innovation refers to the process by which societies develop technologies that facilitate the substitution of relatively abundant factors of production for relatively scarce factors in the economy. It has been substantiated through establishing a correlation between a measure of factor scarcity and an indicator of the direction of technical change (Hayami and Ruttan, 1985). For example, the constraints imposed on agricultural development by an inelastic supply of land have, in countries such as Japan, Taiwan, Korea, and several south Asian countries, been offset by the development of high-yielding crop varieties designed to facilitate the substitution of fertilizer for land. Similarly, the constraints imposed by an inelastic supply of labor, in countries such as the United States, Canada, and Australia, have been offset by technical advances leading to the substitution of mechanical power for labor.

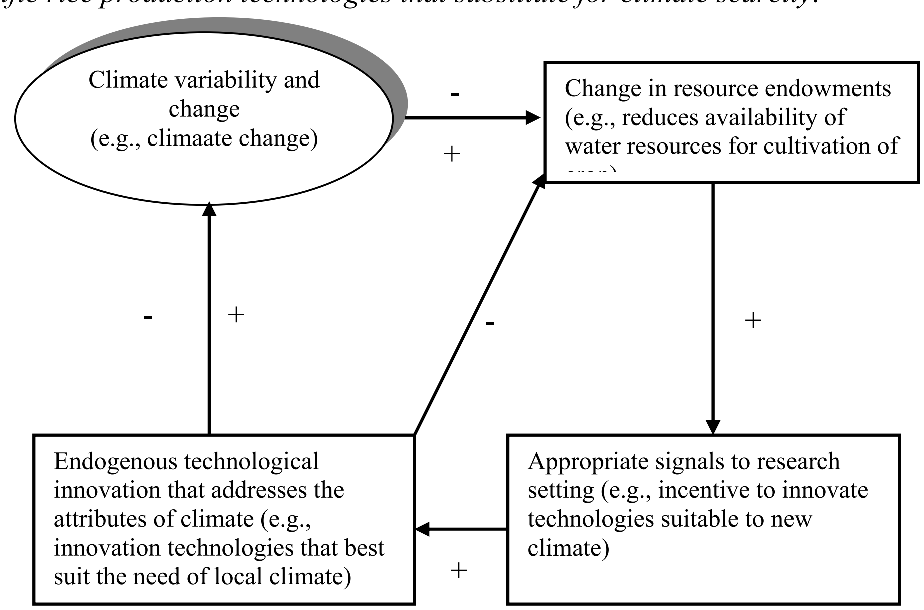
In recent years the hypothesis of induced innovation has emerged as a basis for understanding potential future agricultural adaptation to climate variability and change (Easterling, 1996; Gitay et al., 2001). Its premise concerning the role of climate as a stimulant for technological innovation, however, has gone largely unquestioned because it is a difficult assumption to test. Although climate is an integral part of agricultural production, unlike other factors of production in agriculture (e.g., input of fertilizers and labor), it is not commonly exchanged in the organized market (Abler et al., 2000). Given that climate is unaccounted for by the market, the need for its valuation by farmers and the public institutions during the process of technological innovation is pivotal so as to address the constraint imposed by scarcity of climatic resource. In view of this discussion, reorientation of the way society institutes agricultural research becomes necessary to adapt and/or realize the opportunities for technical change associated with the new climate. Therefore, research effort along the path induced by climatic stress is an essential step to gaining meaningful insights with regard to agricultural adaptation to climate change. Hence the justification for the study of *climate-induced innovation* to assess the role that climate has played in stimulating technological innovation in agriculture

4. CLIMATE-INDUCED INNOVATION

Climate-induced innovation occurs when location-specific climatic constraints are confronted with new technologies in demand. It is vital in Nepal because greater rice yield is desired by all farmers regardless of the climatic conditions in which they grow the crop. Since an optimal cultivation of rice is possible only when climatic conditions are favorable that invariably means an inadequate supply of climatic resources (e.g. rainfall) adversely affects productivity. For example, Kung (1971) showed that an estimated 1300 mm of field water is required during the rice growing season, for optimal production. For this reason, regions with drier climate need to be either compensated through irrigation or provided with low water demanding varieties of rice that are able to produce comparatively equivalent yield even when climatic conditions are not favorable. It is within this premise that the comparison of rice productivity growth across the districts of Nepal with contrasting climates can be instructive in testing the assumption of climate-induced innovation.

According to McCunn and Huffman (2000), when climate-induced innovations occur in agriculture, two outcomes are likely. First, such innovations may advance knowledge to optimize the use of available climatic resources across different regions. Second, it has the potential to enhance the ability of a region to compensate for the constraints imposed by climate and become self-sufficient in agricultural production. In the case of Nepal, climate-induced innovation would provide opportunity for farmers to substitute for climate allowing for increased rice productivity in climatically less favorable regions, leading to a convergence of productivity across districts of Nepal. The potential for convergence of productivity across different climatic regions can only be realized if and when farmers and research establishments devise and adapt technologies appropriate to the climatic as well as societal needs of a region in question.

Although the hypothesis of induced innovation and the convergence are not the same, the test of convergence is justified in the premise that technological innovation made in response to the relative resource endowments of the regions in question will allow climatically marginal regions to 'catch-up' with the climatically favorable regions. It is therefore important to see whether spatial variations in climatic resources condition the regional patterns of investment in rice technologies, and conversely, if the process that constituted adaptation to existing climate might ameliorate the negative effects of future climate change. This necessitates the test of the null hypothesis of this research that *climatic limitations cannot be shown to provide incentives to farmers to urge their supporting institutions to invest in research and development of location-specific rice production technologies that substitute for climate scarcity*.



+ = positive change, - = negative change

Figure I: Conceptual framework: climate-technological interaction

As shown in Figure I, climate change may alter the supply of climatic resources by changing growing season length and soil moisture regimes, and by adding heat stress to plants. Such changes, according to the hypothesis of induced innovation, will provide appropriate signals to farmers and public institutions to induce technologies suitable for the growing environment of the new crop. Translating this argument, as presented in the conceptual model, the hypothesis of induced innovation suggests an important pathway for the interaction of climate and technology, and by extension the test of climate-induced innovation. The strength of this simple framework lies in its ability to highlight the central role of climate as a motivator of technological innovation and ultimately as a source of adaptation to climate change. Within this conceptual framework, I will examine the role of climate variability, with emphasis on the spatial component, as an incentive to the innovation of technologies in the Nepalese agricultural system.

5. NEPAL'S BIOPHYSICAL AND CLIMATIC CHARACTERISTICS

Nepal's diverse terrain is comprised of distinct ecologic regions including the flat plains, or *the Terai*, in the southern part of the country, rising to higher elevations that are categorized sequentially as Middle Mountains or *the Hills* in the middle, and High Himal, or *the Mountains* in the north (see Figure II). The mountain region that lies

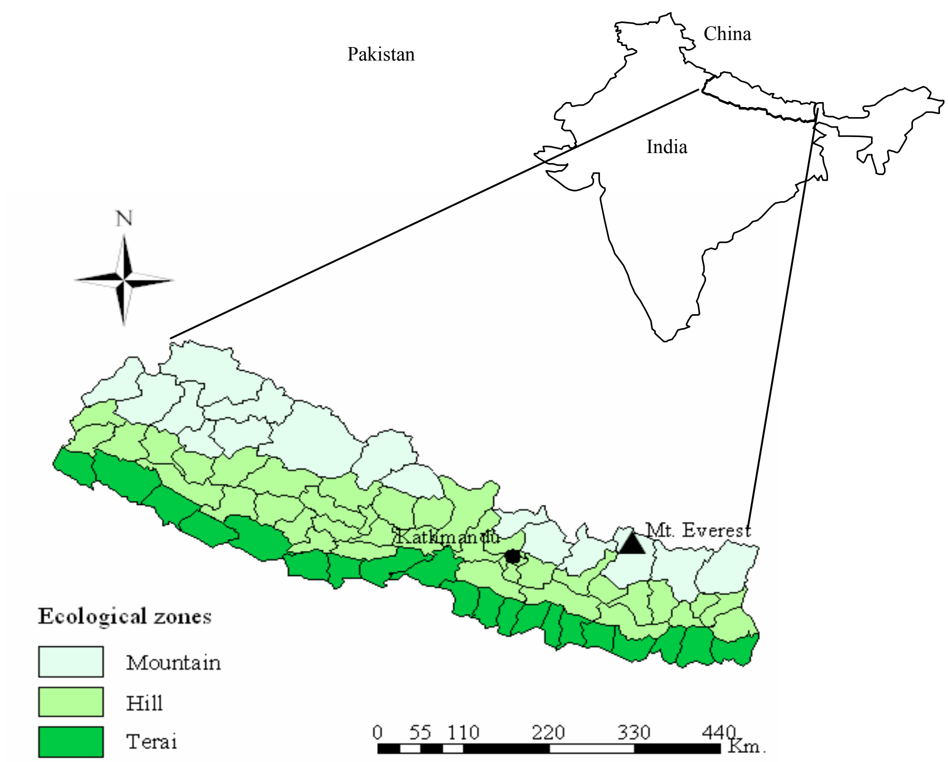


Figure II: Map of Nepal showing three ecological zones (Mountain, Hill, and Terai) above the altitudes of 5000 meters comprises 35 percent of Nepal's 147,181 square kilometers of land. The Hills lie between altitudes of 600 to 5000 meters, and accounts for 42 percent of the total land area. The flat Terai region, a northern extension of Gangatic plain, is located below the 600 meters elevation and comprises 23 percent of the total land area. Each of these regions represents a well defined geographic area with distinct bio-physical characteristics that are significantly different from each other.

The most outstanding feature of Nepal's climate is the monsoon precipitation, which is characterized by two distinct phases: the "wet" and the "dry." The wet phase (June-September) refers to the summer season. Over 75 percent of the annual precipitation occurs during this phase (Shrestha et al., 2000). The monsoon, which is highly variable across space and time, is first experienced in the eastern parts of the country and gradually moves westward with diminishing intensity. The variation in the pattern of rainfall from east to west is substantial and is further accentuated by the diverse terrain within each physiographic belt (Chalise, 1994). The amount of summer monsoon and the number of days with rainfall decreases substantially as it moves to the northwestern part of the country (Chalise and Khanal, 1996). The annual cycle of the monsoon determines the practice of agriculture in Nepal, especially rice cultivation.

In the last three decades the average air temperature measured at 49 stations across Nepal has risen by 1.8^0F (1^0C), this is twice as high as the 1^0F (0.6^0C) average warming for the mid-latitudinal Northern Hemisphere (24 to 40^0N) over the same time period. The temperature differences are most pronounced during the dry winter season, and least when the monsoon peaks (Shrestha et al., 1999). The study by Shrestha et al. shows a significant warming in the higher elevations of the Hills and Mountains in the western half of the country compared to the lower elevations in the south (see Figure III).

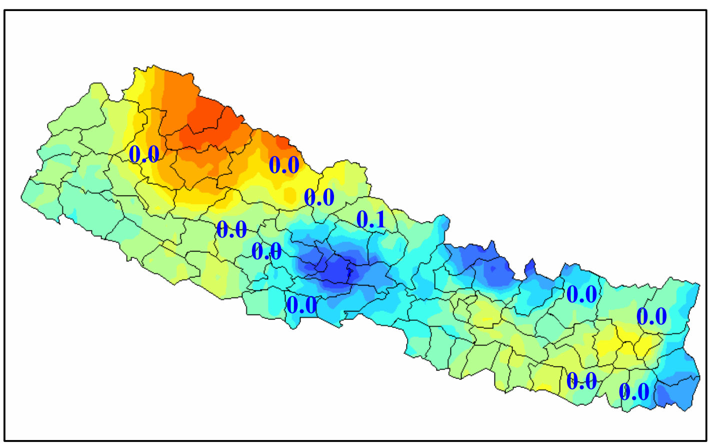


Figure III: Observed pattern of mean annual temperature change in Nepal, 1971-1994 (source: Shrestha et al., 1999) superimposed on mean monsoon rainfall surface created using average monsoon rainfall data from 196 meteorological stations across the country

Similar findings have also been observed by Liu and Chen (2000) on the leeward side of the Himalayas, on the Tibetan Plateau. If the observed trends of temperature change are overlain on the prevailing patterns of rainfall of the country, they reveal a negative association between the amount of rainfall and general trends of warming (see Figure III). For example, the Hills and Mountain regions of the western part of the country, which receive lower average rainfall, exhibit a higher degree of warming compared to the central and eastern Hills and Mountain, which are comparatively wetter.

A recent study using general circulation models (GCMs) also projects a consistent warming of the Himalaya region (Agrawala, et al., 2003). While the study also estimates an overall increase in precipitation, mostly during the monsoon season, it is not clear whether the existing rainfall patterns will remain the same or not. Increase in monsoon precipitation in an area that has already experienced heavy rainfall may lead to more flooding. Conversely, areas with low monsoon rainfall may be subject to dryer conditions in the future.

6. RICE IN NEPAL

Rice is an important staple crop followed by maize, millet, wheat, and barley and it accounts for about 50 percent of both the total agricultural area and production in the country (Pokhrel, 1997). It is grown on about 1.55 million hectares with productivity of 2.85 tons per hectare (HMGN/MOAC, 2002a). Of the total rice cultivated area, 87 percent is in the subtropical climatic region of the Terai and valleys, about 10 percent is grown in the warmer regions of the Hills at altitudes ranging from 1000 to 1400 meters, and about 3 percent is cultivated in the higher altitudes above 1500 and 3050 meters – the highest known elevations in the world where rice can be grown.

The two major rice cultivation practices found in Nepal are irrigated and rainfed wetland (lowland). Both of these practices are common in all three ecological regions. In irrigated areas, water may be added to the rice field during the rice growing season as a supplement to rainfall. However, due to lack of irrigation infrastructure, rainfed wetland cultivation is the dominant practice for about 66 percent of the rice area (Pokhrel, 1997). Traditionally, rice is sown in seedbeds in late spring or early summer. Once the rice seedlings complete 3-6 weeks, depending on the availability of water, they are transplanted to the main field. The edges of the terraces are raised with earth bund to retain rain water, and those with access to irrigation are flooded through gravity fed channels. In the rainfed condition the access water from rainfall is retained.

7. AGRICULTURAL RESEARCH AND DEVELOPMENT IN NEPAL

Concerted effort in research and development of agricultural technologies in the country began after the establishment of research stations and farms in 1960s (Yadav, 1987). In 1987, the country reformed its agricultural research establishment further to form the National Agricultural Research Council (NARC) - an independent research body mandated to conduct agricultural research and development (R&D) activities in the country.

NARC has been responsible for developing technologies that are sensitive to the need of the Nepalese farmers. There are 18 Regional Agricultural Research Stations

(RARSs) located in the various agro-climatic regions of the country. The RARSs conduct research and outreach activities based on the climatic and socioeconomic needs of the farmers (Gauchan and Yokoyama, 1999). Responsibilities are decentralized to ensure that the individual RARS have flexibility to design and develop climatically appropriate cropping technologies. Promising technologies developed through the NARC systems are disseminated to the farmers' fields through district-level government extension agents located in each of the 75 districts. These new technologies are first demonstrated in small plots with the active participation of farmers. The district level extension workers not only provide active supervision of these demonstrations but also work as liaison between NARC and farmers. This feedback mechanism between the farmers and the research institutions allows researchers to incorporate specific needs of the farmers in their research and technology development.

Furthermore, after the establishment of a democratic government in 1991, Nepal initiated a 20-year Agricultural Perspective Plan (APP) with the objective of alleviating poverty through the development of agriculture. The multiphase APP envisages a five percent increase in the annual growth rate of agricultural production and a doubling of per capita food availability (HMG/ADB, 1995). The plan also aims to improve the supply of agricultural inputs (e.g., fertilizers, improved seeds and pesticides), increased availability of credit, improved irrigation infrastructure, generation of technology suitable for specific climatic niches, and creation of markets for agricultural products. However, the real questions still remain: *do differences in climate across regions (districts), particularly differences in rainfall and other biophysical conditions, influence innovation in agricultural technology? Will innovation in rice growing technologies keep pace with the more rapid climate change as the one in the recent past?* The importance of these questions underscores the essence of this research as it relates to the understanding of the impacts of and adaptation to climate change in rice-based cropping systems in Nepal.

8. UNIT OF ANALYSIS, DATA & VARIABLES, AND THEIR SOURCES

8.1. Unit of analysis

The district for which data on rice productivity and irrigation acreage are available is the primary spatial unit of analysis in this study. Of the total 75 districts of Nepal (39 in the Hills, 20 in the flat Terai, and 16 in the Mountain regions), 73 districts are included in this study. The districts of Mustang and Manang within the Mountain region are not included since no rice is grown there. The choice of the district as the unit of spatial analysis is further justified because it is the smallest level that contains the full complement of government administrative services. For example, in the agriculture sector, every district has a government run Agricultural Development Office (ADO) that employs agricultural extension workers responsible for promoting improved technologies. Each district is also supplemented by the office of the Agricultural Input Corporation (AIC) and the Agricultural Development Bank (ADB), government subsidiaries established to market agro-technologies to the farmers. In addition, the Department of Irrigation (DOI) has its offices at the district level which is responsible for developing irrigation infrastructure. All these agencies are pivotal in the development of specific agricultural technologies needed in various agro-climatic regions of Nepal.

8.2. Data and variables

Table I presents a list of variables included in this study and their sources. Average rice yield is the dependent variable. Climate, biophysical, and socioeconomic factors determine the productivity of rice and form the independent variables. In the following paragraphs I discuss each of these variables separately.

8.2.1. Rice yield: The test of convergence using rice yield is justified on the basis that rice has always been a focus of innovation, primarily because of the introduction of Green Revolution techniques in neighboring India (Thapa, 1994). During the decade of the 1990s, average yield of rice in Nepal grew by 1.33 percent. In some parts of the country, it rose as much as 3.6 percent, while in others the growth was nominal (Goletti et al., 2001). This growth is largely attributed to the adoption of a new generation of rice varieties, the improvement of farmers' crop management practices, and the increased use of irrigation, fertilizer, and other agrochemicals in rice production (HMG/ADB, 1995; Gruhn et al., 2003). However, the important question is whether the districts with comparatively less favorable climate are taking advantage of new innovation in technologies.

Variable	Definition	Dimensions
Dependent - Rice yield	Net yield kg/ha	Time series
Independent - Biophysical		
Average monsoon rainfall	Arithmetic average	30 years average
Ecological zone	Terai, Hill, and Mountains	Biophysical
Gradient of slope	Area with >45% slope	Biophysical
Independent - Socioeconomic		
Irrigation	% of net rice area under irrigation	Time series
Built-up area	% of total area with infrastructure	Cross section
Population	Rate of population growth between 1991 to 2001	Tome series

Table I: Variables included in the analysis of rice productivity convergence across the districts of Nepal

8.2.2. Rainfall: The amount, timing, and duration of monsoon rainfall significantly affect rice production in Nepal. It is defined as the average rainfall that occurs during the period of the monsoon (June, July, August, and September). The average cumulative monsoon rainfall over a 30-year period from 1968-1997[1] has been

[1] According to World Meteorological Organization, an average of 30 years of continuous records is taken as normal. Only 89 meteorological stations in Nepal have rainfall records for such a long period of time. Therefore, many other stations having records for less than 30 years have had to be included.

taken to represent Nepal's rainfall variable. Although this variable is derived from a long-term average, it has no time series variation, and has one value per district.

8.2.3. Slope gradient: The gradient (slope) is an important biophysical factor that creates different underlying conditions for rice production. The higher the gradient the less favorable it becomes for rice cultivation. Although the farmers of Nepal have, for centuries, carved out the hill slopes to form rice terraces primarily to retain water, higher gradient makes it difficult to establish terraces that can hold water for long periods of time, a necessary condition for rice production. The gradient of land is measured as the fraction of area greater than 45 percent slope..

8.2.4. Ecological regions: Nepal's three ecological regions (Terai, Hills, and Mountain) provide a standardized framework for characterizing bio-physical conditions of the country and have traditionally been used to plan crop production potential of the country. For example, the four objectives outlined by the first comprehensive agricultural development plan of the country (the Ten-Year Agricultural Plan, 1975-1985) prioritized the fertile Terai and the valley bottoms for high input agriculture such as grain production; the Hills for fruit and vegetable production, and the Mountains for livestock development (Yadav, 1987). This macro-level policy, according to HMG/ADB (1995) has remained largely unchanged and continues to be the core strategy of the recent twenty-year plan (1995-2015). For this reason, the ecological zones of Nepal are used as a proxy for biophysical condition, and have been identified by creating dummy variables (Terai = 0, Hills and Mountain = 1).

8.2.5. Irrigation: Irrigation mediates the relationship between climate and agriculture production and has become a widely used substitute in areas where soil moisture is inadequate for crop growth and development (Easterling et al., 2004). Irrigation is not an innovative technology *per se* the presence of irrigation alleviates the problem of water scarcity, a major constraint in the implementation of improved technologies, such as high yielding varieties (HYVs) and the use of chemical fertilizers. In the past 25 years, the government of Nepal made major investments in irrigation with significant focus in the 1990s (HMG/MOAC, 2002b). In this study irrigated land refers to the area with access to irrigation facilities including those that have water throughout the year as well as those that it only during the rice growing season. To make interpretation of the results more practical, I transformed the net irrigated area as a percentage of the total rice cultivated area by dividing the total irrigated area by the total rice area.

8.2.6. Built-up area: Built-up area, defined here as an area covered by building and man-made infrastructure such as roads and airports, is the indicator of general development of a region in question. The importance of good infrastructure for agricultural development is widely recognized. In Nepal, as anywhere in the world, growth in rice productivity depends on existence of rural infrastructure, a well functioning domestic market, and access to appropriate technology. While the state of infrastructure varies widely across the country, most districts in the Mountain and the Hill region have very low built-up area. In the case of Nepal's rice farming system, this translate to lack of inputs, little or no spatial and temporal integration, and weak internal competitiveness, all of which are pivotal in productivity growth. For this reason, built-up area is included to represent the economic environment of districts in question.

8.2.7. Population growth rate: Following Boserup (1965) research on demographic change and agricultural development centers around the issue of the pressure of population on resources in agrarian societies. In the short term, population growth may simply involve using more labor per unit area. However, increased use of labor alone does not meet the ever increasing demand for food. Eventually, this signals the farmers and research institutions to innovate technologies in order to overcome such situations. For this reason population growth rate between the census of 1991 and 2001 for each district has been included to understand the role of population growth in the convergence of rice productivity in Nepal.

8.3. Sources of data

This study is based on secondary data obtained from the various agencies of the government of Nepal. The data concerning rice yield (productivity and yield are used interchangeably to indicate mean output per unit of land) and irrigation were obtained from the Nepal Agricultural Database (NAD) of the Ministry of Agriculture and Co-operatives (MOAC). The data on average monthly rainfall is obtained from the Department of Hydrology and Meteorology (DOHM). The DOHM has compiled the average monthly precipitation for the period of 1968 through 1997 recorded at various meteorological stations throughout the country, and is used to represent the monsoon rainfall in this analysis. Date from Global Land Cover Characterization (GLC2000) which provides global and regional land cover classification at approximately 90x90 meter grid cell were extracted to calculate the percentage of slope gradient and built-up area of a district (see http://www-gvm.jrc.it/glc2000.htm) for detail discussion of the data). The data on population growth is calculated using the absolute change in population between the two census of 1991 and 2001.

9. METHODOLOGICAL APPROACH

Following Barro and Sala-I-Martin (1992), convergence can be understood in two different ways – convergence in terms of degree of productivity differentials and growth rates – and are referred to as *sigma (σ)* and *beta (β) convergence*, respectively (Barro and Sala-I-Martin, 1992). First, I will analyze the σ-convergence by examining measure of spread of the rice productivity at aggregate (national) and disaggregate (ecological region) scales. Following Sala-I-Martin (1996), σ-convergence occurs when the dispersion in rice productivity across 73 districts of Nepal tends to decrease over time.

That is, if

$$\sigma_{it+T} < \sigma_{it} \tag{1}$$

where, σ_{it} is the dispersion of rice yield (y_{it}) across districts $_i$ at the initial period and σ_{it+T} is the dispersion of rice yield across districts at subsequent periods.

Convergence of σ may be a necessary condition but it is not a sufficient condition to generate β-convergence (Islam, 2003). The analysis of σ-convergence does not reveal whether there is a tendency for districts with relatively low initial rice productivity to catch up with districts that have relatively higher initial rice productivity. For this reason I investigate whether Nepal's rice productivity over time demonstrates the presence of β-convergence as well. From the conceptual perspective, two methods for the test of β-convergence are prevalent in the literature and are termed as *absolute* and *conditional* convergence (De la Fuente, 1997). Absolute convergence, also known as unconditional convergence is defined as the tendency towards equalization of productivity, where regions with low productivity at the initial stage will grow faster to catch-up with the one with greater initial productivity (Islam, 2003).

The rationale for absolute β-convergence lies on the relative homogeneity of the factors of production across the districts of Nepal. In agriculture where productivity is determined by myriads of factors including biophysical and climatic condition, absolute β-convergence is not sufficient (McCunn and Huffman, 2000), hence the scenario of conditional β-convergence. As discussed earlier, the Terai region of Nepal is favorably endowed for rice production compared to the high altitude region of the Hills and the Mountain. If the districts with less favorable climates receive appropriate responses from the public institutions responsible for devising technologies, then there should still be convergence to the same growth trajectories, not just necessarily at the same level of rice productivity as those districts with favorable climates. For this reason a conditional convergence model with dummy variable (Terai = 0, otherwise = 1) of the following form is estimated:

$$(1/T)\ \ln(y_{it+T/}\ y_{it0}) = \alpha + \beta\ln(y_{it0}) + \gamma\mathrm{H} + \delta\mathrm{M} + \varepsilon_{i0,T} \qquad (2)$$

where, $(1/T)\ \ln(y_{it+T/}\ y_{it0})$ is the natural logarithm of district *i's* average rice productivity growth from *0* to *T*, in which $y_{i,t+T}$ measure average productivity in district *i* between *0* and *T* and y_{it0} measures the rice productivity at district *i* during base year of 1991/92. The parameter α, is the intercept term and $\varepsilon_{i0,T}$ represents the average of the error term, ε_{it}, between time *0* and *T*, and γH and δM represent the Hills and the Mountain dummy where the Terai is considered as the reference region. The sign of the β coefficient indicates either convergence or divergence. Negative and significant sign of the β coefficient indicates convergence whereas a positive sign indicates divergence. Absence of either signs on β coefficients indicates that neither convergence nor divergence has occurred. If there is an occurrence of β convergence it implies that over time, districts with comparatively lower initial rice productivity have increased their rate of production relatively faster than districts with higher initial productivity.

The conditional convergence with dummy variable model asserts that Nepal's ecological regions can have different productivity levels, but as long as technological innovation is induced by differences in climate resource, they should eventually grow at the same growth trajectory. But the limitation of dummy variable model is that it cannot account for the role of district specific factors, climatic and otherwise, that may have influenced the rice productivity from converging to a same growth trajectory. For example, if districts with favorable climate (e.g. rainfall) have increased their advantage over the districts with less favorable climate, intuitively it shows complementarities between technology and climate (Mendelsohn et al., 2001). It also rejects the notion that scarcity of climatic resource acts to spur technological innovation to substitute for climatic resources, hence providing **no** support for the climate-induced innovation discussed earlier. In order to test for the existence of climate-induced innovation, a subsequent conditional β convergence model with additional explanatory variables of the following forms is estimated:

$$(1/T)\ \ln(y_{it+T/}\ y_{it0}) = \alpha + \beta\mathrm{l}(y_{it0}) + \kappa_i X_i + \lambda_i K_i + \psi_i Z_{it+T} + \gamma\mathrm{H} + \delta\mathrm{M} + \varepsilon_{i0,T} \qquad (3)$$

where, $\kappa_i X_i$ represent the biophysical variables (average monsoon rainfall and slope), $\lambda_i K_i$ is the socioeconomic variables (built-up are and population growth rate), and $\psi_i Z_{it+T}$ represent the average growth rate of irrigated area as a percentage of total rice cultivated area between *0* and *T*. A positive and significant value of the coefficient of biophysical variables indicate that districts with relatively better resource endowments (e.g. higher monsoon, less slope) produce significantly higher amounts of rice compared to those districts with lesser resource endowments. In other words, there is a direct complementary between climate and technology. However, the opposite is true if the sign of the coefficient is insignificant, implying that technology is substituting for climate.

In convergence literature, it is customary to estimate the speed of convergence which is estimated by making use of the coefficient of β obtained by running growth initial level regression (Barro and Sala-I-Martin, 1995). Following McErlean and Wu (2003) the speed of convergence (commonly referred to as implied β) across the districts of Nepal is computed as:

$$\hat{\beta} = -\ln(1+\beta)/T \qquad (4)$$

where $\hat{\beta}$ is the estimated coefficient that shows the rate of convergence, β is the coefficient of growth-initial level regression, and *T* represent the length of the study period. A positive and significant value of estimated $\hat{\beta}$ (i.e., $\beta<0$) in growth of initial level regression is a necessary condition for rice productivity convergence. If the estimated β is negative (i.e., $\beta>0$) and significant then divergence is accepted. Likewise when the coefficient of estimated β is insignificant, neither convergence nor divergence is accepted (McErlean and Wu, 2003). If convergence in rice productivity across the districts of Nepal is to occur then districts with low rice productivity at the initial year must exhibit greater rates of growth compared to the growth rates of those districts with higher initial level of productivity.

10. RESULTS

10.1. Summary statistics

Figure IV displays the spatial pattern of rice productivity for the year 1991/92 and 2002/03, the beginning and the end of the study period. It is apparent from the map that there is a wide variation in rice productivity across the districts of Nepal. Three districts in the central Hill region (Kathmandu, Lalitpur, and Bhaktapur) rank among the highest rice-producing areas in the country with yields of over 5.0 t/ha. They are followed by four districts in the central Terai region (Bara, Parsa, Rautaht, and Chitwan), with yields of little over 3.0 t/ha. In contrast, over 50 percent of the other districts, most of them in the western half of the country, produce less than the national average of 2.0 t/ha of rice.

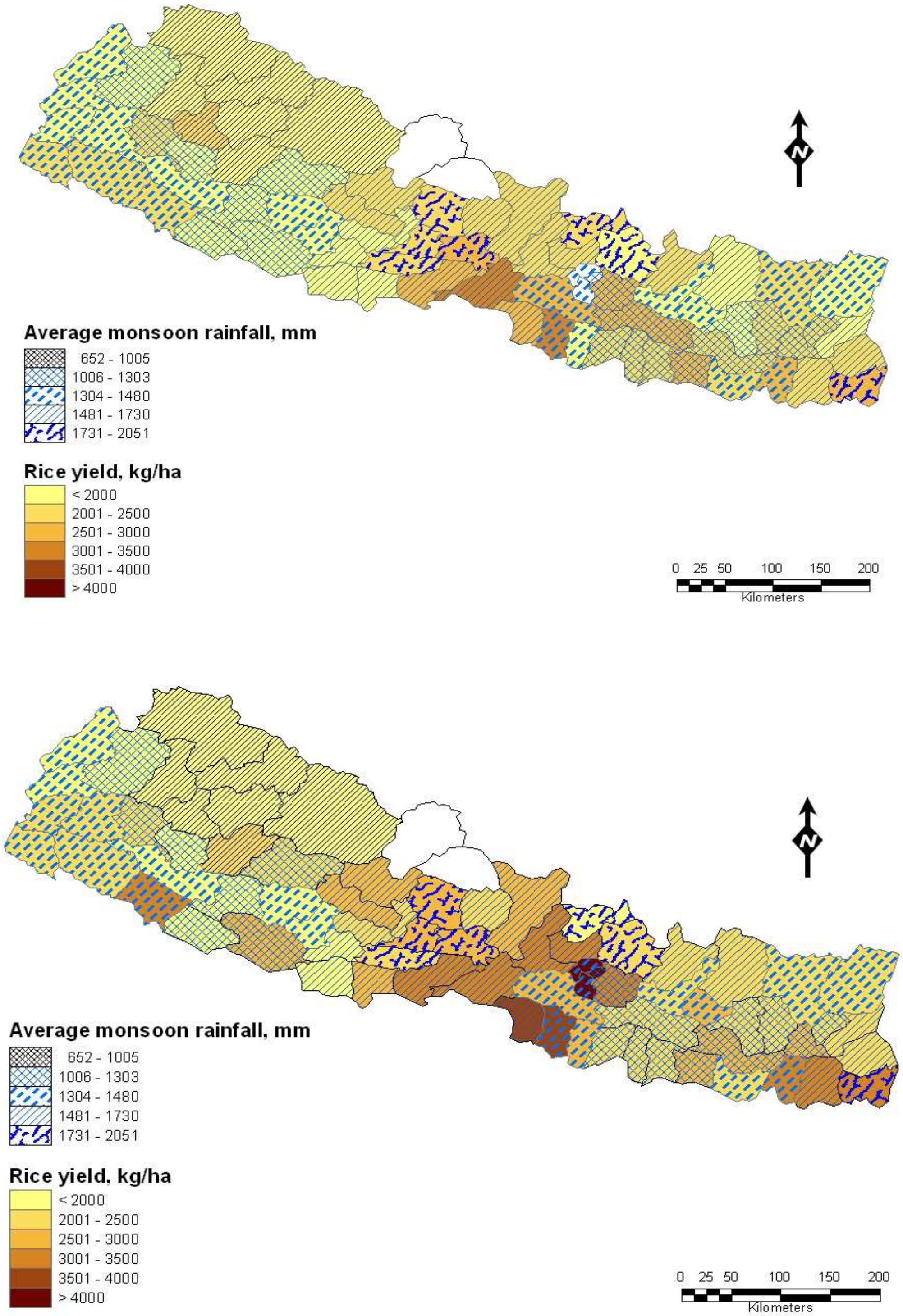


Figure IV: Average rice yield during the calendar year of 1991/92 and 2002/03 overlain with average monsoon rainfall across the 73 districts of Nepal

Districts with low productivity also correspond with areas that receive lower average monsoon precipitation, indicating a direct association between rainfall (an important climate variable) and rice productivity.

The spatial patterns of rice productivity during the year 2002/03 indicate that the number of districts with darker shades of brown have increased considerably indicating that more districts are now producing greater than average rice yield compared to 1991/92. Though the previously high yielding districts in the central Hill region have maintained their overall lead, more districts are now catching up. This trend is particularly noticeable in two clusters of districts. One of the clusters is in the western part of the country and the other is in the mid-eastern part of the country. Both clusters are also ranked as regions with low monsoon precipitation. The emerging patterns of rice productivity growth in climatically marginal regions may be the outcome of conscious policy choice to invest more heavily in regions that are not well endowed agro-climatically.

Figure V displays the average rice productivity trends across different geographic scales. At the national level, on average, rice productivity increased from 2,164 kg/ha in 1991/92 to 2,497 kg/ha in 2002/03, with an average annual growth rate of 1.49 percent. In the Terai, where over 70 percent of rice is produced, the yield increased from 2,268 kg/ha in 1991/92 to 2,718 kg/ha in 2002/03, averaging an annual growth rate of 2.19 percent, the highest among the three ecological zones. In the Hill region, where rice is the second most important crop after maize, yield increased from 2,229 kg/ha in 1991/92 to 2,615 kg/ha in 2002/03, an average of 1.57 percent annual growth rate. During the same period, the growth rate in the Mountain region was fairly small, averaging only 0.31 percent per year, the lowest among the ecological zones. While the overall increase in rice productivity is impressive, disaggregated analysis at the ecological level (Terai, Hill, and Mountain) shows a substantial regional variation.

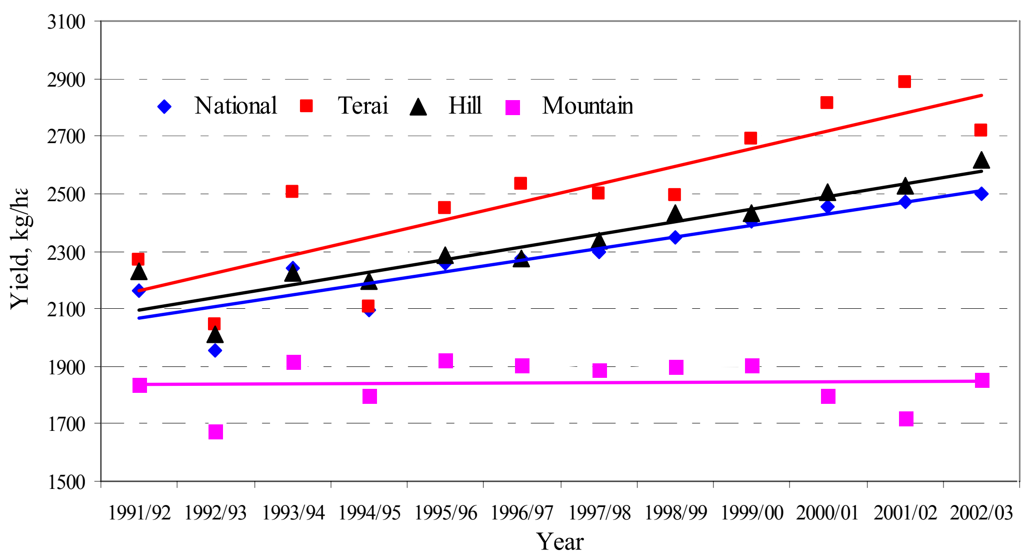


Figure V: Rice productivity trends at the national and regional level, 1991/92-2002/03

10.2. Test of σ-convergence

In general, there have been no distinct patterns to suggest the occurrence of *σ*-convergence in rice productivity because the CVs have not reduced substantially across the districts of Nepal during the 12 years. In aggregate, the CV in 1991/92 was 31.7 percent and continued to decline until 1996/97, with a record low in 1995/96 (22.6 percent). The trend reversed thereafter, reaching an all time high of 33.9 percent in 2002/03. The finding at the aggregate level does not preclude the fact that *σ*-convergence may not have occurred within a specific ecological region. It is therefore important to assess the evolution of CVs at the scale of ecological regions to see if the pattern observed at the national (coarse-scale) level is also found within the ecological (finer-scale) regions.

Figure VI present the general trends of the evolution of CVs over time in the three ecological regions of Nepal. Although fluctuating, over time the CVs have declined in 20 districts of the Terai region. From a high of 26.3 percent in 1991/92, the CVs have declined to a low of 7.6 percent in 1996/97. With the exception of 2002/03, all the other years show relatively lower CVs, hovering around 10 percent. At the same time, CVs in the 36 districts of the Hills have remained constant (at around 30 percent), and present no evidence of either *σ*-convergence or *σ*-divergence. In the Mountains, however, the evolution of the CVs, from a low of 5.3 percent in 1996/97 to a high of 29.8 percent in 2001/02, show an overall *σ*-divergence and shows that rice productivity became more variable across the 14 districts of this region.

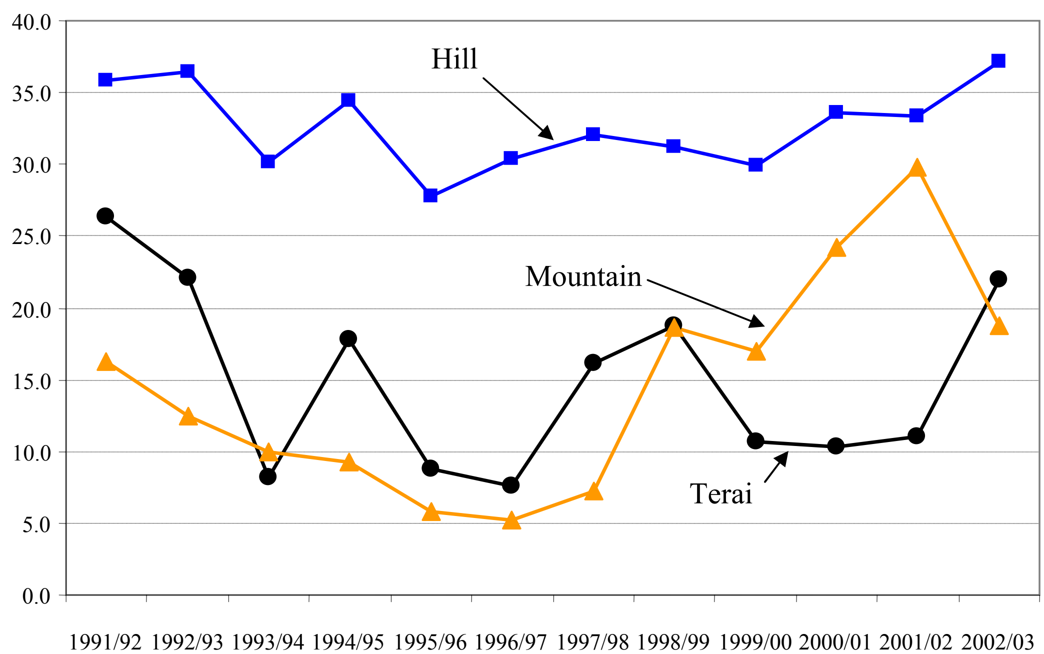


Figure VI: Distribution of sigma as measured by the coefficient of variation across the three ecological regions of Nepal, 1991/92 to 2002/03

Many factors may have been responsible for the apparent lack of *σ*-convergence across the districts of Nepal, including variability of the monsoon rainfall. During the year of 2002/03, rice planting was delayed by two to three weeks in the eastern part of the country due to delayed rainfall. At the same time, districts in the central Terai region suffered from flooding due to excessive precipitation during the early stage of tillering. Likewise, due to weak monsoon in June of the same year, farmers in many low-rainfall region of the country (especially mid- and far-western regions) could not begin their rice planting activities at the normal time. However, the Hill region in the central part of the country received timely and favorable monsoon rains. The consequence of variable monsoon pattern observed in this particular year may have been partly responsible for increasing CVs across the districts of Nepal.

10.3. Test of β convergence

While *σ*-convergence and *β*-convergence are related, it is possible to observe *β*-convergence without the presence of *σ*-convergence (Sala-I-Martin, 1996; Bernard and Durlauf, 1996). In this research, *β*–convergence provides an impartial test which asserts that over time districts with comparatively lower initial productivity levels have increased their rate of production relatively faster than those with higher initial productivity. Existence of convergence is judged by the sign of the *β* coefficient – a negative and significant sign of the *β* coefficient obtained by running *growth-initial level* regression is a condition for convergence.

I begin this analysis by presenting the *β*-convergence coefficient of the dummy variable model. The qualitative variables such as the three ecological zones (Terai, Hill, and Mountain) are transformed into quantitative ones and used as predictors in the regression analysis. This provides a way to analyze rice productivity across the districts that share some common characteristics. For example, the Hills and the Mountains are differentiated from the Terai because they have different biophysical characteristics. Due to its favorable biophysical condition for rice cultivation the Terai region is considered as the reference region. If the estimated coefficient of the Hills and the Mountains regions show no significant difference in rice productivity growth then the assumption of single equilibrium state is accepted.

Table II presents the estimate of the dummy variable model. The sign of the implied *β*-coefficient in the model is in tandem with the overall expectation, i.e., negative and statistically significant ($p<0.001$). The amount of variation explained by R^2 is 50 percent and the F statistics is 25.1, $p<.001$. The estimated *β*-convergence coefficient implies that, on average, the speed of convergence across the districts of the Mountain and the Hills is greater by about five percent as compared to the districts in the Terai region. Net of the other factors, the estimates of implied *β* reveals that rice productivity growth rates across the districts of the Hills and the Mountain regions are greater indicating that the districts with the unfavorable climate are catching up with the reference region of the Terai. Despite this increased growth rate, however, the Hills and the Mountain regions are still lagging behind in closing the gaps with the reference region. Average rice productivity growth rates across the 39 districts in the Hills remains about 7 percent below that of the Terai and is marginally significant ($p <0.05$). The corresponding figure in the Mountain region remained 19 percent below the referenced region, and is statistically highly significant ($p<0.001$).

Parameters	Estimates of the β–convergence coefficients	
	Conditional	
	Dummy variables	Explanatory variables
Implied β	-0.43(-8.27)***	-0.69(-13.42)***
Hill (Yes=1, No=0)	-0.07(-2.28)**	0.008(1.18)
Mountain (Yes=1, No=0)	-0.19(-4.75)***	-0.11(-2.06)
Average monsoon rainfall		0.00006(1.39)
% of irrigated rice land		0.002(2.44)*
Gradient of slope >45%		0.001(1.25)
Built-up area		0.015(5.58)***
Population growth rate		0.05(2.83)**
Estimated β	0.047	0.097
Number of observations	73	73
Constant	3.45(8.54)***	5.02(13.35)***
F ratio	25.11***	25.99***
R^2	0.50	0.74

*=p <0.05 **=p<0.01 ***=p<0.001

Table II: Estimates of β-convergence coefficient for rice productivity across districts of Nepal, 1991/92-2002/03. Number in the parenthesis is the t-values.

The second column of Table II reports the estimates of βs with additional explanatory variables. The amount of variation explained by R^2 is 74 percent and the F statistics is 25.9 (p<.001), and the signs of the coefficients are as expected. After controlling for both biophysical and socioeconomic variables the results show a greater rate of β-convergence. The estimate of the conditional β-convergence coefficient implies that the rate of rice productivity growth across the districts of the Hills and the Mountains is higher when compared with the Terai, indicating that the districts with lower rice productivity at time t_0 increases their growth rate by about 10 percent per year.

Although it is marginally significant (p <0.05), the relationship between increased percentage of rice growing areas under irrigation and rice productivity is positive. As discussed earlier rice productivity in Nepal is inherently sensitive to monsoon climate, its vulnerability to uncertainty in monsoon rainfall depends on many factors, including whether or not irrigation is in use. It is possible that with assured irrigation, farmers may have additionally committed more production inputs (e.g.

fertilizers) leading to increased production in climatically less endowed regions. Likewise, the effects of climate variability, as translated in the form of variations in the amount of monsoon rains is insignificant in explaining the variations in rice productivity growth rates across the districts of Nepal. Inadequacy of monsoon rainfall may have been compensated by means of irrigation.

Interestingly the gradient of slope is a weak predictor to explain the variability of rice productivity across the districts of Nepal. The two socioeconomic variables, however, show a strong influence on productivity growth rates. One percent increase in built-up area contributed one and half percent in rice productivity growth rates (p <0.001). Likewise, population growth rate also has a positive contribution in rice productivity (p <0.01). These findings are consistent with the study by McKinsey and Evenson (1998), which measures the intra-country agricultural productivity differentials in India. Their study shows that Green Revolution had greater impacts districts connected with infrastructure were associated with higher productivity. The authors argue that the differences have persisted over a long period and are associated with the discrepancy of investment in research and development activities in marginal areas.

When controlling for both biophysical and socioeconomic variable the results suggest that growth in rice productivity across the districts of the Hills and the Terai are statistically the same. The corresponding figure of the Mountains (-0.11 percent, p <0.001), however, shows that this region lags behind. One of the principal characteristics of the Mountain region, in addition to its overall marginal climate with low temperatures, is the relatively small fraction of arable land available for rice cultivation. In contrast, the Terai and the Hills have a more favorable climate with higher temperatures and a higher percentage of arable land under rice. The better soil quality and warm climate of the valley bottoms of the Hills and the Terai offer a greater potential for rice production, making investment of infrastructure and technology more efficient. This may explain the inherent difference of rice productivity in the Mountain region of Nepal.

While the empirical result suggests that there no direct complementarities between climate, especially variability in monsoon rainfall, and rice productivity growth rates across the districts of Nepal, it is important to check for spatial dependence to confirm this finding. A hypothesis of *no* spatial dependence was tested using the residuals from the conditional β-convergence model. Specifically, the *Morans's I* measure of the indication of spatial dependencies in error terms were checked with residual against spatially weighted residuals. As illustrated in Figure VII, the value of Moran's I (0.11) signals a weak association between rice productivity growth rates and rainfall, reaffirming the earlier finding that there is no direct complementarities between rice productivity growth rates and the variability of monsoon rainfall in across the districts of Nepal.

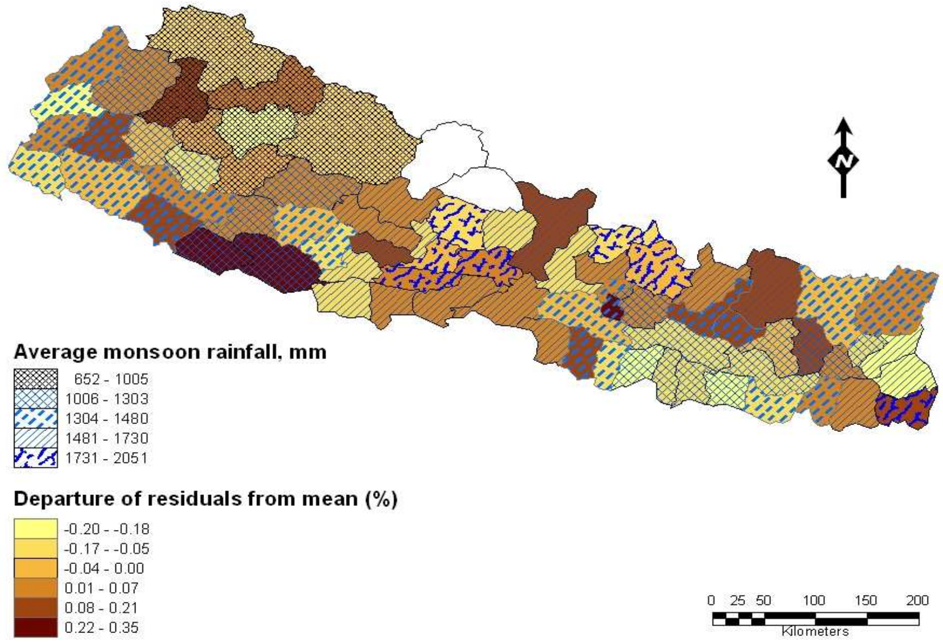


Figure VII: Map of residuals based on the conditional model

11. DISCUSSIONS

The test of convergence shows that rice productivity across the 73 districts of Nepal is converging to a common growth trajectory indicating that the districts with lower rice productivity are catching up. This process may have been driven by several factors including the development of varieties targeted to specific climatic condition. As shown in Table III, agricultural research establishments in Nepal have released over 40 new varieties of rice since it started its formal research and development program in the country (HMG/MOAC, 2002). While the significant number of varieties were targeted for high potential irrigated land (e.g., 13 for the Terai and the fertile valleys and 11 for the Hills), a number of varieties were also developed for rainfed climate having intermittent drought periods.

During the 1990s, Nepal made significant changes in agricultural research and development, one of which was the decentralization of its research activities (Biggs and Gauchan, 2001). Many new actors such as non-governmental organizations (NGOs) and private enterprises emerged to take active roles in Nepal's agricultural research and development (Gauchan et al., 2003). As a result an alternative institutional model in research and development known as Participatory Technology Development (PTD) emerged. The main appeal of PTD has been its promise to improve the adoption rates of appropriate technologies in climatically marginalized regions to increase food security and alleviate poverty, through better partnership with all stakeholders in agricultural development including farmers (Witcombe et al., 1996).

Recommended ecological domain	# of varieties released	Crop characteristics	Yield potential (Mt)
Terai under irrigated condition	3	Medium maturity (145-160 days)	4.0-4.5
Terai and valleys under irrigated condition	10	Early maturing (118-135 days)	3.5-4.8
Mid hills under partially irrigated condition	11	Early/mid maturity (130-155 days)	3.5-4.9
Terai and valleys under rainfed condition	3	Medium maturity (145-160 days)	4.5-5.6
Hill under rainfed condition	4	Medium maturity (145-160 days)	3.2-4.5
High hills, cold tolerant, under rainfed	3	Late maturity (165-180 days)	4.2-5.0

Table III: Improved varieties of rice released by the agricultural research systems of Nepal in the last 35 years

Source: HMG/MOAC, Agri-Business Promotion and Statistical Division, 2001/02

The new institutional framework of PTD has enhanced the relationship between NARC and other actors in agriculture thereby facilitating the process to devise location-specific technologies in agriculture. In recent time non-governmental organizations (NGOs) have grown into strong research bodies, an unlikely configuration a decade ago. For example, NARC is jointly working with the Local Initiative for Biodiversity Research and Development (LI-BIRD), an NGO experienced in participatory approach to innovation of technologies in agriculture. One of the important characteristics that distinguish PTD from conventional approach of R&D is that researchers work on objectives established by the farmers (Sperling and Ashby, 1999).

In Nepal, PTD is used as a complement for popularizing varieties that are appropriate for climatically marginal regions (Witcombe et al., 1996). For example, through their joint undertaking, LARC and LI-BIRD have developed cold tolerant and disease resistant rice varieties that are also high yielding (Sthapit et al., 1996). Two high altitude rice varieties (*Machhapuchre-3* and *Machhapuchre-9*) were released in the mid 1990s (Sthapit et al., 1999). A recent study found that *Machhapuchre-3* rice variety was significantly superior to local varieties producing 42 percent greater yield in rice growing areas situated between 1500 to 2200 meters above sea level (Joshi et al, 2001). Similarly, *Machhapuchre-9* was found to be doing well in areas located at altitudes greater than 2200 meters above seal level. Although both of these varieties are prone to seed shattering (tendency for grains to drop during harvesting) compared to the local ones, this trait has not prevented farmers from widely adopting the new varieties because the disadvantage is outweighed by the higher yield and better quality (Joshi et al., 2001). According to Sah et al., (2004), other varieties (*Lumle 1-9-1*, *LR 93002*, and *Lumle1-1-1*) have also been found to tolerate cold temperature better during anthesis than local ones. Some of these varieties are found to be most appropriate for low rainfall areas in the western mountain regions of the country.

Aside from work on varietal improvement discussed above, researchers in Nepal are also engaged in devising agronomic practices that alleviates the constraints posed by climate. For example, in order to maximize yield potential of HYVs farmers must follow a complex set of recommendations, one of which is the timing of planting. Failure to do so may result in substantial loss of yield. HYVs are very sensitive to the planting dates and age of the seedling. Studies shows that improved varieties of rice must be transplanted from the seed bed to the main field between 24-28 days in order to achieve maximum yield potential (Mahato and Pathic, 1997). In a country where the timing and intensity of monsoon precipitation is highly variable, such a stringent condition may be problematic.

In order to address the constant dilemma associated with the uncertainty of the onset of monsoon, researchers are improvising traditional method of "direct seeding" often practiced in risk prone environments (Pandey and Velasco, 2002). According to Pandey and Velasco, the development of suitable varieties, availability of modern tools (e.g., power tiller drill), and increased access to herbicides has made this traditional technology more profitable in risk prone environment of many Asian countries including Nepal. This method has not only reduced the demand on labor but has thrived in areas of erratic rainfall especially during the early stages of crop development. According to Tripathi et al. (2004), economic analysis of direct seeding yielded an additional net return of 33 percent compared to the conventional method of transplanting.

Parallel to the government's effort in developing technologies for improving production in agriculture, there has been a significant policy change that may have contributed to the observed growth in rice productivity. One of the most important policy changes with regard to rice productivity has been the decision by the government to deregulate the fertilizer policy in 1997. This change in policy has (i) allowed the private sectors to import and distribute fertilizers; (ii) phase out a fertilizer subsidy, and (iii) deregulate fertilizer prices. In the absence of detailed data it is difficult to precisely assess the impacts of the deregulation policy on the fertilizer use by the farmers. Nonetheless, a recent study based on the analysis of household level data collected from 986 farmers indicated a significant growth in the application of fertilizer by the farmers of Nepal (Gruhn et al., 2003). According to this study 81 percent of the farmers applied both inorganic and organic fertilizers during the 2001/02 crop year and reported increased supply of fertilizer, something they had not experienced previously.

12. CONCLUSIONS

Though the uncertainty associated with climate change and reliance on mechanistic assumptions limits our ability to understand how farmers may adapt (Easterling et al., 2004), by assessing climate-technology interaction in Nepal's rice farming system this research provides a new dimension by which adaptation to climate change can be examined. Analysis of productivity convergence, even indirectly, implies that technological changes can be represented by examining the direction of productivity over time and is an attempt to approximate the *ultimate* impacts of climate-induced innovation in agriculture. In fact, the finding offers insights for refining our existing understanding of agricultural adaptation to climate variability and change. More specifically, by adding climate, this study stretched the boundary of the hypothesis of induced innovations to understand the process by which agriculture might adapt to changing climatic conditions.

I find a significant shift in the operational mandate of the research establishment. For example, the PTD approach within the institutional framework of Nepal's premier public research institution in agriculture such as NARC has created an environment that allows others non-state actors, such as NGOs, to participate in research and technology development. This partnership has encouraged NGOs and other organizations to become strong research institutions contributing significantly to innovations of technologies in agriculture. The role of farmers in technological innovation has also grown significantly whereby they are now able to set their agendas based on their own resource endowments, which is facilitated by NARC and NGOs. This new institutional approach has not only improved relationship between farmers and researchers, but has created an environment of dialogue that has benefited both partners. The impact of PTD is reported to be especially positive in rice production in climatically marginal regions (Sthapit et al., 1996).

The new institutional framework for research and development of technology in a country that is climatically diverse is in line with the argument made by Hayami and Ruttan (1985). They postulated that the cost of devising location-specific technologies is greater for a country with a wide range of climatic variation than for a more geographically homogeneous one. As a climatically diverse and yet economically challenged nation, the cost of devising technologies appropriate for all agro-ecosystems is enormous and may hinder desired growth in agricultural productivity in Nepal. Therefore, involving multiple actors in the development of agricultural technologies in Nepal is necessary to mitigate this cost. The recent institutional change in Nepal's research establishment, which has favored partnership with NGOs, farmers, and private sectors, has worked to everyone's advantage. It has been cost-effective, location-specific, and intensive as it involves both farmers and researchers every step of the way in developing technological innovations.

To summarize, the findings from both the empirical and the qualitative assessment indicate that Nepal's research establishment is engaged in and committed to the development of location-specific technologies that address the constraints of climate. The development of technological innovations accompanied by change in policies in agriculture may have been responsible for higher rice productivity among the districts with marginal climate. This assertion is not only supported by results of the empirical analysis, which shows evidence of rice productivity convergence, but also by qualitative assessment of the case studies, which shows development of technological innovations geared towards addressing the limitations of climatic resources in rice production. This kind of change, which is more participatory and interactive than has traditionally been the norm in research establishments, shows hope of likely adaptation to climate change in the future.

Based on these findings, I assert that, in response to future climate change, farmers and their supporting public institutions in Nepal will continue to modify their cropping activities to new climatic conditions, thereby mitigating potentially negative effects in much the same manner that they have demonstrated at present. This finding should not, however, lead to complacency as innovations in agriculture have always depended upon continued investment in agricultural research and infrastructure. Yet, the current trend of weaning resources away from agricultural and climate research, especially in developing countries, endangers the vital support provided by public institutions for farmers to adapt to climate change. Therefore, agricultural adaptation to future climate is contingent upon continued investment in agriculture as well as active engagement of public institutions responsible for developing and disseminating appropriate technologies for farmers operating in specific climatic regions. I argue that if research establishment and farmers have made appropriate responses to improve their capacity to respond to climatic constraints then they are generally better prepared to adapt to changing climate.

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