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Roads, Population Pressures, and Deforestation in Thailand, 1976–89

Population pressures play less of a role in deforestation than earlier studies of Thailand found.

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Summary findings

Between 1976 and 1989, Thailand lost 28 percent of its forest cover. To analyze how road building, population pressure, and geophysical factors affected deforestation in Thailand during that period, Cropper, Griffiths, and Mani develop a model in which the amount of land cleared, the number of agricultural households, and the size of the road network are jointly determined.

The model assumes that the amount of land cleared reflects an equilibrium in the land market. Hence, in the long run, the amount cleared depends on the profitability of agriculture and on the long-run costs of clearing. The size of the country's agricultural population, as well as the size of the road network, affects the demand for cleared land and hence the amount cleared in equilibrium.

The authors estimate an equation to explain the amount of land cleared in equilibrium, using data for the 58 provinces that were forested in 1973. Data from five years (1976, 1978, 1982, 1985, and 1989) are combined to estimate the equilibrium model.

They find that the number of agricultural households and road density both increase the fraction of each provinced cleared, but their effects are small. The elasticity of cleared land with respect to agricultural households is only 0.12; with respect to road density, it is only 0.26.

These effects do differ by region, however; moreover, the elasticities of forest area with respect to population density and road density are larger in absolute value than the respective elasticities for cleared land. The elasticity of forest-to-total area with respect to population density is -0.41 for the North/Northeast section of the country and -0.22 for the South/Central region. The corresponding elasticities with respect to road density are -0.20 and -1.09.

This suggests that population pressures play less of a role in deforestation than earlier studies of Thailand found. For an area to remain deforested, it must be profitable to convert the land to another use, and that use is usually agriculture. Steep slopes and poor soil quality provide some natural protection for forests, although the quantitative impact of those factors vary. Variations in agricultural prices also affect the amount of deforestation.

This paper — a product of the Environment, Infrastructure, and Agriculture Division, Policy Research Department — is part of a larger effort in the Department to understand the forces affecting land use change. The study was funded by the Bank's Research Support Budget under research project "Population Growth and the Environment" (RPO678-59). Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington DC 20433-0001. Please contact Anna Marie Marañon, room N10-031, telephone 202-473-9074, fax 202-522-3230, internet address amaranon@worldbank.org. February 1997. (48 pages)

Roads, Population Pressures and Deforestation in Thailand, 1976-1989

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I. INTRODUCTION

Tropical deforestation is considered to be one of the major environmental disasters of the 20th century, yet there have been few careful studies of its causes. This paper examines the causes of deforestation in Thailand between 1976 and 1989, a period when the country lost 28% of its forest cover. The perspective taken in the paper is that, in the long run, the determinants of deforestation are the determinants of land use change. While logging and fuelwood gathering may remove forest cover, regrowth will occur, at least in moist tropical forests. For an area to remain deforested, it must be profitable to convert the land to another use, and this use is usually agriculture. In Thailand, for example, agricultural land increased by 13.12 million hectares (82 million rai in the local unit of measurement[1]) between 1961 and 1988. During the same period, forest land decreased by 13.6 million hectares (or 85 million rai). This paper focuses on what, in equilibrium, determines the amount of land cleared for agriculture.

In any area the amount of land cleared for agriculture is likely to be determined simultaneously with the agricultural population of the area, especially if land is farmed by small subsistence farmers, and with the density of the road network. We therefore develop an equilibrium model of cleared land--more accurately, the ratio of cleared to total land--agricultural population density and road density. The underlying determinants of these variables are factors that determine the profitability of agriculture in an area: soil quality, topography, agricultural prices, general population growth and the growth of the non-agricultural sector.

What we would like to emphasize is the quantitative impact of two forces--roads and population pressures--that increase the profitability of converting forest land to agriculture. In

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[1] 1 rai 0.16 hectares.

other parts of the world, most notably Brazil and Belize, there is well documented evidence that roads have opened up forest areas to markets and have increased the profitability of deforestation. In the Brazilian Amazon, roadbuilding was part of a deliberate government strategy to develop the region (Pfaff 1994, Mahar 1989). As aerial maps clearly show, development has followed road networks. In the case of Belize, proximity to roads has been shown, not surprisingly, to have a larger impact on commercial agriculture than on subsistence agriculture (Chomitz and Gray 1995). Moreover, the magnitude of the impact of roads depends on soil quality along the road.

In the case of Thailand, the government undertook a road-building program in the Northeast section of the country in the 1970's. The purpose was to encourage settlement of that region of the country as a bulwark against communist encroachment from Laos. Road building very likely spurred deforestation in the Northeast during the 1970's and 1980's; however, we do not know the magnitude of its impact.

Thailand also experienced rapid population growth during this period, which may have contributed to deforestation in two ways. First, a growing population demands more food, which increases the demand for agricultural land. Second, and perhaps more importantly, in rural areas where other economic opportunities are limited and squatters are permitted on forest lands, a growing population may increase the demand for land for subsistence agriculture. This is reported to have been the case in Thailand. In the North of Thailand, for example, deforestation is attributed in part to shifting cultivation practiced both by lowland farmers and hill people (Feeney 1988). The Northeast, although geographically less favorable for farming, also experienced population expansion and agricultural settlement owing to pressures on land elsewhere in the country.

The question is how large an impact increases in agricultural households have had on deforestation. One would expect deforestation to increase with the number of agricultural households; however, it might increase at a decreasing rate. When land is plentiful and tenure rights are insecure, it is common for farmers to practice swidden agriculture--to farm land for several years, mining the nutrients in the soil, and then leave the land fallow for a period. In the classic studies of cropping practices by Boserup (1965) and Pingali et al. (1987), however, the intensity with which land is farmed increases with population density, implying that increases in population may increase the demand for land at a decreasing rate.

The impact of roads and population pressures on deforestation are of interest because, at least in part, these factors are subject to government control. Equally important in influencing the extent of deforestation are physiographic factors that affect the cost of clearing land and that affect its suitability for agriculture--topography, nutrients in the soil, how well the soil drains. Indeed, it is likely that these factors mitigate the impact of roads and population pressures on deforestation.

A. Methodology

To examine the impact of road building, population growth and physical factors on deforestation, we develop a model of equilibrium in the market for cleared land. The demand for cleared land is based on the profit-maximizing behavior of a typical farmer and is then aggregated across all agricultural households in a county. The aggregate demand for cleared land in a county increases with the number of agricultural households in a county, with the price of agricultural output, with average soil quality in the county and with ease of access to roads. The supply of cleared land increases with factors that lower the cost of clearing land, for example, the slope of forested land.

Equilibrium in the market for cleared land yields a reduced-form equation for the amount of land cleared in each province. Since this is likely to be determined simultaneously with the number of agricultural households and with the road network, structural equations are also specified for these variables. For purposes of estimation, all equations are scaled by the area of the province.

The cleared land equation is estimated by two-stage least squares using data for the 58 provinces (changwats) in Thailand that were forested in 1973. Data from five years (1976, 1978, 1982, 1985 and 1989) are pooled to estimate the model, which is then used to predict the fraction of land cleared in each province in 1991.[2]

B. Main Findings

Our main findings are as follows: Although road density and agricultural household density both increase the fraction of land cleared in a province, the impact of these variables is small. The elasticity of cleared land with respect to agricultural households is only 0.12, while it is 0.26 for road density. To appreciate the size of these coefficients, consider the impact of a change in road density and agricultural population in Mae Hong Song, a province in northern Thailand on the border of Myanmar. In 1991, 72% of Mae Hong Song (9,130 sq. km.) was under forest cover. Agricultural household density was 1.8 households per square kilometer (km^2) and road density 0.06 km of roads per square kilometer. According to our model, an

[2]These years are determined by the availability of landsat images showing the extent of forest cover in each province.

increase in agricultural household density from 1.8 households per km^2 to 6.8 households per km^2 would result in only 524 square kilometers of deforestation. The effect of increasing road density from 0.06 km of roads per km^2 to 0.10 km of roads per km^2 would be to deforest only 703 square kilometers of the province.

From a policy perspective it is important to understand the quantitative impact of two forces--roads and population pressures--that increase the profitability of converting forest land to agriculture. Our analysis suggests that the quantitative impact is much smaller than suggested by previous studies of Thailand by Panayotou and Sungsuwan (1994) and Panayotou (1989) who have shown the elasticity of cleared land with respect to population density to be as high as 1.5 in Northeastern Thailand in the 1973-82 period. If the elasticities are closer to those that we estimate, this suggests that commercial rather than subsistence agriculture may have been responsible for much of the land clearing in Thailand. We are, however, precluded from testing this hypothesis by lack of reliable, spatially disaggregated data on agricultural prices.

The paper is organized as follows: Section II describes alternative approaches to modeling deforestation that have been followed in the literature and presents the model that forms the basis for our empirical work. Section III presents the stylized facts about deforestation in Thailand. Our empirical results are presented in Section IV, and our conclusion in Section V.

II. A THEORETICAL MODEL OF TROPICAL DEFORESTATION

In modeling land use change, it is possible to take either a spatial or a non-spatial approach. Spatial models, which follow von Thunen, emphasize the heterogeneous nature of land, and explain variations in the price of land and land use as a function of land characteristics, most notably, distance to markets. In a typical spatial model a plot of land will be devoted to agriculture (as opposed to forest) if the profits from agriculture exceed the value of keeping land under forest cover. In general, the probability that agriculture yields a higher return than forestry increases with ease of access to markets, with better soil quality, and with higher agricultural prices. If one has data at a spatially disaggregated level, then a logit model can be used to predict equilibrium land use for individual plots of land, as a function of the distance of the plot from markets, soil quality and input and output prices (Chomitz and Gray 1995).

Spatial models are certainly appropriate if one has spatial data, and are especially useful in explaining the spatial pattern of deforestation--how likely deforestation is to occur as a function of distance from roads, or to vary with soil quality. To estimate spatial models using aggregate (i.e., county-level) data, one must assume a distribution of unobservable land characteristics and estimate a model that predicts the proportion of a county or province under forest cover (Panayotou and Sungsuwan 1994; Reis and Margulis 1991; Southgate, Sierra and Brown 1991 Stavins and Jaffee 1992) or the fraction of a county converted from forest to agriculture (Pfaff 1994).

The drawbacks of such an approach are two-fold: First, it is difficult to incorporate population variables in spatial models, except in an ad hoc fashion.[3] Second, in equilibrium

[3]To elaborate on the first point, the strength of models that emphasize the heterogeneous nature of goods (e.g., hedonic models and bid-rent models) is that they can predict how price varies with the characteristics of the good. They are not, however, good at explaining how shifts in the quantity demanded or supplied influences price, or in describing the quantity of goods produced. Changes in population affect deforestation primarily by shifting the demand for cultivated land and the supply of deforested land, but, for this reason, are difficult to incorporate in von Thunen models. In these models population must enter through the price of agricultural goods or the wage (by shifting the supply of labor).

models in which the dependent variable is the ratio of forest to total area, population is determined simultaneously with land use and the endogeneity of population must be reflected in estimation of the model. To remedy these problems we model deforestation using a non-spatial model of the demand and supply of cleared land, which leads to a reduced-form equation for the amount of cleared land. This is supplemented by equations that describe the number of agricultural households and the road network.

A. Equilibrium in the Market for Cleared Land

We assume that the amount of land cleared for agriculture is determined by the interaction of the demand for cleared land, which is based on individual farmers' profit maximizing decisions, and the supply of cleared land, which is given by the inverse of the marginal cost of clearing function. Although the farmer may himself clear the land and then farm it, it is conceptually convenient to break the decision into two parts: how much land will be cleared at each price and how much land will be demanded for agricultural use at each price. The equilibrium amount of land cleared and its price are then determined by the intersection of demand and supply.

The farmer's demand for cleared land is a function of its price, the cost of other inputs (labor and capital), the price of agricultural outputs and factors that affect the productivity of land for agriculture, such as soil quality and slope. The farmer's static profit maximizing problem is given by:

$$\underset{(l,k,L_C)}{MAX} \quad \Pi = (p - t) \cdot y(l,k,L_C,Q,s) - wl - rk - P_C L_C \tag{1}$$

where

p	= agricultural output price
t	= transport costs
y	= production function for agricultural output
l	= labor
k	= capital
L_C	= cleared land
Q	= soil quality
s	= slope
w	= wage rate
r	= rental rate on capital
P_C	= price of cleared agricultural land

Solving the first-order conditions to (1) yields a demand function for cleared land,

$$L_c = f(p, t, w, r, P_c, Q, s) \quad (2)$$

which depends on the price of agricultural output, transport costs, the wage rate, the rental rate of capital, the price of agricultural land, soil quality and slope. To derive the aggregate demand for cleared land in the county, C^D, we multiply (2) by N, the number of agricultural households in the county,

$$C^D = NL_C(p, t, w, r, P_C, Q, s) \quad (3)$$

The supply function of cleared land is the inverse of the marginal cost of clearing function. The cost of clearing land depends on physiographic factors such as slope, as well as on the cost of labor and other inputs. Since these costs depend on the accessibility of areas to be cleared, the size of the road network may also affect the cost of clearing agricultural land. The marginal cost of clearing function is given by

$$M = M\ (\ C^S,\ s,\ R,\ w\ ) \qquad (4)$$

where

C^S	= supply of cleared land
s	= slope (e.g., area in various slope categories)
R	= km of roads
w	= wage rate.

The amount of land that is cleared in a county in equilibrium is the value of C that equates the supply of cleared land to the aggregate demand for it. Equations (3) and (4) thus determine C and its price. If the price of cleared land were observed, one could attempt to estimate the demand and supply curves for cleared land. Because it is not, we estimate instead a reduced-form equation for the equilibrium level of cleared land. The model implies that cleared land should depend on the number of agricultural households in a county, N, on ease of access of land to markets (t), on soil quality, agricultural prices in the county, on the wage and cost of capital, and on variables that affect the cost of clearing land--the extent of the road network, and the slope of land. The cleared land equation is thus given by

$$C = C\ (\ p,\ t,\ w,\ r,\ Q,\ s,\ R,\ N\ ) \qquad (5)$$

In equation (5) it is possible that agricultural population (N) and roads (R) are determined simultaneously with land use; hence the endogeneity of population and roads must be clearly reflected in the estimation of the model. We therefore construct equations that determine the number of agricultural households and length of roads in a province.

B. The Agricultural Household Equation

In modeling the number of agricultural households in a province we take the total number of households in the province as given and model the probability that a household engages in agriculture as a function of the difference between returns to agriculture and income in the non-agricultural sector. Income in agriculture should depend on existing infrastructure (roads), physiographic factors (soil and slope), the price of agricultural output and the amount of cleared land (a proxy for its price). Income outside of agriculture is captured by non-agricultural Gross Provincial Product (GPP).

The number of agricultural households in a province can be written as the product of the number of households in the province times a function of the incomes in agricultural and non-agricultural occupations. Replacing the former by its determinants yields equation (6), the number of agricultural households as a function of total households, roads, cleared land, soil quality, slope, and agricultural prices and non-agricultural Gross Provincial Product,

$$N = T * g\ (R, C, Q, s, p, t, GPP) \tag{6}$$

where:

T = total number of households
R = roads
C = cleared land
Q = soil quality
s = slope

p = agricultural price
t = transport costs
GPP = non-agricultural Gross Provincial Product per household.

C. The Road Equation

Although there is no well-developed theory of road building, it is reasonable to assume that the equilibrium size of the road network depends on the cost of road construction and on the demand for transportation. The cost of road construction should depend on input prices (cost of labor, earth-moving equipment and materials) as well as on physiographic factors. As Chomitz and Gray (1995) have suggested, roads are usually built where the terrain is conducive to them--in flat areas where the soil drains well and flooding is not a problem. One measure of topography is the amount of land in each province in a particular slope category. The effect of slope on the length of the road network is unclear. Holding demand constant, the presence of physical barriers may require that more kilometers of roads be built in a hilly province than in a flat one. On the other hand, the presence of mountains raises the cost of connecting two areas and thus makes it less likely that the areas will be connected. The cost of road building will also depend on whether land has been cleared of forests, and, hence, on the amount of cleared land in the province.

The demand for roads may be influenced by factors outside of a particular province, by military requirements of the government (e.g., the desire to contain political insurgency in the Northeast of Thailand) or by a deliberate attempt to encourage development of an area (as in the case of the Brazilian Amazon). It is also likely to depend on provincial conditions as well. These include the population of the province and its spatial distribution and (depending on how roads are financed) on provincial income, which we approximate by non-agricultural GPP.

These considerations suggest that the size of the road network in a province (in km) may be expressed as:

$$R = h\ (T,\ d,\ s,\ C,\ GPP) \tag{7}$$

where

T = total number of households
d = distance from Bangkok
s = slope
C = cleared land (sq. km.)
GPP = non-agricultural GPP per household

D. Econometric Specification of the Model

Equations (5), (6) and (7) constitute a simultaneous equation system in three endogenous variables: cleared land, agricultural household and roads. Since cleared land, agricultural population and the road network are all likely to vary with the area of the province, it seems reasonable to divide these variables, as well as others that vary with the size of the province, by provincial area. This implies that the dependent variables are now percent of the province cleared, agricultural household density and road density. Likewise, slope and soils are now the percent of each province in particular slope and soil quality categories.

For purposes of estimation, the simplest forms of (5)-(7) are the linear approximations given in (5')-(7'). Note that in equations (5')-(7'), the wage and the rental rate of capital have been dropped, since these variables are not available at the provincial level. The cost of transporting goods to market (t) is approximated by d, distance of the province from Bangkok (for exports) and by the size of the road network (R) for output sold within the province. Since rice accounts for 60-70 percent of the acreage planted during the period of this study, the empirical counterpart of p is the price of rice. The three equations are then:

$$(5') \quad (C/A)_{it} = a_0 + a_1 (N/A)_{it} + a_2 (R/A)_{it} + a_3 Price_{it} + a_4 Distance_i + a_5 (\%Soil)_i + a_6 (\%Slope)_i + U_{1,it}$$

$$(6') \quad (N/A)_{it} = b_0 + b_1 (R/A)_{it} + b_2 (C/A)_{it} + b_3 Price_{it} + b_4 Distance_i + b_5 (\%Soil)_i + b_6 (\%Slope)_i + b_7 (T/A)_{it} + b_8 (GPP/T)_{it} + U_{2,it}$$

$$(7') \quad (R/A)_{it} = c_0 + c_1 (C/A)_{it} + c_2 (\%Slope)_i + c_3 Distance_i + c_4 (T/A)_{it} + c_5 (GPP/T)_{it} + U_{3,it}$$

It is easy to verify that the model of equations (5') - (7') is not identified. Equation (6') violates the rank condition for identification, as does equation (5'), if non-agricultural output per household enters the road density equation. To ensure that the first two equations are identified, it is sufficient to add a variable to the road density equation that does not enter the cleared land or agricultural household density equations. One candidate is the product of % Slope and Distance from Bangkok, which captures the notion that physical barriers are more of an obstacle to road building the more remote the province.

With this modification. the model (5')-(7') can be estimated consistently via Two-Stage Least Squares. A question of interest is how sensitive the estimated coefficients are to the choice of instrumental variables. To explore this, we estimate variants of the model that include total household density squared and non-agricultural GPP per household squared in the agricultural household density and road density equations. We also use as instruments the product of household density squared and non-agricultural GPP per household squared in the agricultural household density and road density equations. We also use as instruments the product of Distance and Total Households (Distance * T/A) and Distance and non-agricultural Gross Provincial Product per household (Distance * GPP/T). For each choice of instruments, a Hausman test is performed to determine whether the three equations are indeed simultaneously determined.

E. Estimation of the Model

The model is estimated for the 58 provinces containing forest land in 1973. It is essential that the model be restricted to these provinces since the dependent variable, percent of the province cleared, is, in actuality, the percent of the province that is not forested. The model is estimated using data from the years 1976, 1978, 1982, 1985 and 1989--the years for which we have information on forest stock and all other variables. (The data used to estimate the model are described in Appendix A.) In each version of the equation dummy variables are added for the various periods and for the regions of the country. The price of rice is also interacted with regional dummies.

Before describing our empirical results, we attempt to give the reader a feel for some of the stylized facts regarding land use changes in Thailand over the two decades of the study.

III. DEFORESTATION AND LAND USE CHANGE IN THAILAND

A. Overview of Thai Agriculture

Over the last 40 years Thailand has experienced dramatic economic growth and has joined the ranks of newly industrialized economies. In spite of rapid industrialization, however, Thailand remains a largely rural country. In 1990, 70 percent of its population was classified as living in rural areas and 64 percent of the labor force was classified as working in agriculture.

Thailand is typically divided into 4 regions, the North, Northeast, Central Plain and South (see Figure 1). The Central region of the country, with about one-third of the country's population, has the best land and is the most densely populated.[4] It is the wealthiest region of the country outside of Bangkok. Agriculture in the Central Plain is primarily commercial, with the majority of agricultural acreage devoted to rice, and the remainder in maize, cassava and sugarcane (see Table 1, which describes agricultural land use in 1978, 1983 and 1993).

The Northeast, which has about 35 percent of the country's population, is less densely populated than the Central region, and has some of the poorest quality land in the country. It also depends more on subsistence agriculture than the Central and Southern regions. During the period of our study, over 70 percent of the land in the Northeast was devoted to rice, with cassava and field corn accounting for the remaining acreage.

The North is the largest region in terms of land area, but, with 20 percent of Thailand's population, is the least densely populated. The soil quality is slightly better than the Northeast, but much of the agricultural land is devoted to subsistence agriculture. In the early 1980's (see Table 2) about 65 percent of agricultural acreage was devoted to rice, 20 percent to field corn and 10 percent to mung beans. Since then, corn has been replaced by other crops.

The South, a mountainous peninsula connected to Malaysia at its southern tip, is the smallest in physical size of the four areas. It contains 13 percent of the country's population, is

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[4]The proportion of Thailand's population living in each region of the country has remained approximately constant since 1960 (Panayotou 1991).

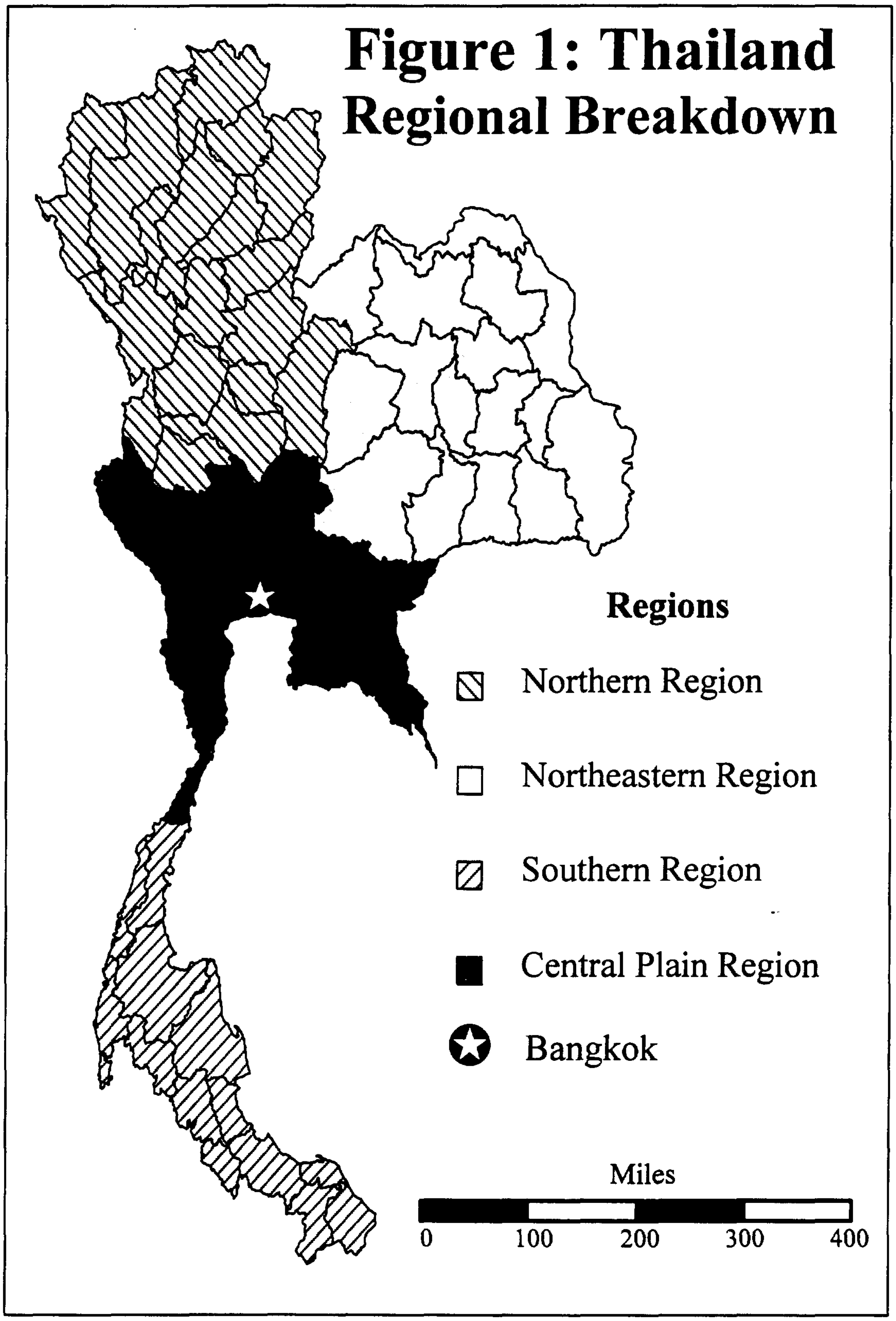
Figure 1: Thailand
Regional Breakdown
Regions
Northern Region
Northeastern Region
Southern Region
Central Plain Region
Bangkok
Miles
0
100
200
300
400

Table 1: Agricultural Land Use, 1978, 1983 and 1993

(as a percentage of the total region)

	North	Northeast	Central	South	Kingdom
1978					
Rice	67.5	83.8	66.7	49.6	72.4
Field Corn	17.8	4.5	8.7	0.2	8.3
Cassava	0.9	10.4	9.9	0.1	7.0
Sugarcane	1.7	0.7	9.6	0.0	3.1
Para Rubber	0.0	0.0	1.6	49.8	5.3
Mung Bean	10.8	0.2	2.9	0.2	3.4
Cotton	0.4	0.2	0.4	0.0	0.3
Tobacco	0.8	0.1	0.1	0.1	0.3
Total	100.0	100.0	100.0	100.0	100.0
1983					
Rice	63.4	78.5	66.5	43.8	68.5
Field Corn	21.3	6.6	8.4	0.1	10.0
Cassava	2.0	13.2	10.0	0.0	8.4
Sugarcane	2.0	1.2	10.3	0.0	3.5
Para Rubber	0.0	0.0	2.3	55.4	6.0
Mung Bean	9.4	0.2	1.8	0.6	2.8
Cotton	0.4	0.0	0.6	0.0	0.3
Tobacco	1.6	0.3	0.1	0.0	0.5
Total	100.0	100.0	100.0	100.0	100.0
1993					
Rice	63.3	71.0	54.5	17.7	58.9
Field Corn	13.8	3.6	7.7	0.3	6.1
Cassava	5.2	11.8	7.3	0.0	7.9
Sugarcane	4.7	2.6	11.2	0.0	4.4
Para Rubber	0.0	0.3	3.0	52.1	7.8
Others	13.1	10.7	16.2	29.8	14.9
Total	100.0	100.0	100.0	100.0	100.0

Source: The Census of Agriculture, 1978. 1983 Intercensal Survey of Agriculture. Advanced Report: 1993 Agricultural Census

Table 2: Forest Area in Thailand, 1973-1991

	Year	North	Northeast	Central	South	Entire Kingdom
Total Area	*km^2*	**169,644**	**168,854**	**103,900**	**70,715**	**513,115**
Forest Area	*1973*	**113,595**	**50,671**	**39,006**	**18,435**	**221,707**
	1976	**102,327**	**41,494**	**34,457**	**20,139**	**198,417**
	1978	**94,937**	**31,221**	**31,463**	**17,603**	**175,224**
	1982	**87,756**	**25,886**	**26,516**	**16,442**	**156,600**
	1985	**84,126**	**25,580**	**25,675**	**15,485**	**150,866**
	1988	**80,402**	**23,693**	**25,078**	**14,630**	**143,803**
	1989	**80,222**	**23,586**	**25,009**	**14,600**	**143,417**
	1991	**77,143**	**21,799**	**24,307**	**13,449**	**136,698**

Source: Royal Forestry Department

Table 3: Percentage of Cleared Land in Thailand (1973-91)

Region	1973	1982	1991
North	33.0	48.3	54.5
Northeast	66.8	84.7	86.9
South	67.4	76.9	81.1
Central	67.6	80.5	82.8
Kingdom Total	54.9	69.5	73.3

Note: Cleared Land is defined as Total Area-Forest Area.

slightly less densely populated than the Northeast, and has soil quality similar to that in the North. Agricultural production is largely commercial, with over half of all acreage devoted to rubber production. Rice, which accounted for just under half of agricultural acreage in 1973, has declined steadily in importance.

Between 1973 and 1991, Thailand lost over 38 percent of its forest cover. In 1973, approximately half of the country's forest area was concentrated in the North of Thailand (the 17 provinces shown on the map in Figure 1), with a quarter of remaining forest area situated in the 16 Northeastern provinces. During the following 20 years the North lost more forest area than any region of the country (approximately 36,000 square kilometers), but the Northeast experienced the greatest percentage deforestation, losing 60 percent of its forest area (28,872 square kilometers).

An alternative way of presenting the data in Table 2 is in terms of the complement of forest area--cleared land. Table 3 presents the ratio of cleared (i.e., non-forested) land to the total area of each region. If population pressures and roads are important determinants of land clearing, one would expect that areas with a higher ratio of cleared to total area to be characterized by higher population density and higher road density. Inspection of Tables 4 (Agricultural Household Density) and 5 (Road Density) provide some support for this hypothesis. In 1982 and 1991, the fraction of land cleared is, of all regions, lowest in the North of Thailand and highest in the Northeast. In these years agricultural household density is also the lowest in the North and highest in the Northeast. The region with lowest road density is also the North. The pattern is not, however, perfect. In 1973, the North and South had approximately equal agricultural household densities; however, a much larger fraction of the South was cleared.

Table 4 : Agricultural Household Density in Thailand (1973-91)

Region	1973	1982	1991	Percentage Change 1973-1991
North	6.1	7.6	8.8	43.8
Northeast	10.1	13.3	17.3	70.4
South	6.6	7.2	12.7	90.7
Central	8.2	9.7	11.4	39.9
Kingdom Total	7.8	9.7	12.5	60.2

Table 5: Total Road Density in Thailand* (1973-91)

Region	1973	1982	1991	Percentage Change 1973-1991
North	0.07	0.11	0.12	84.9
Northeast	0.09	0.13	0.18	102.0
South	0.09	0.13	0.15	67.5
Central	0.11	0.16	0.15	43.8
Kingdom	0.08	0.13	0.15	78.5

*(Kilometers of Road per Square Kilometer of Land Area)

Similar anomalies exist with respect to the South and Central regions in 1973. The Central region had both higher population and road density than the South, yet a similar fraction of cleared land.

This suggests that the relationship between cleared land, roads and population requires more careful analysis, which is presented in the next section.

IV. EMPIRICAL ANALYSIS

In discussing our results we focus on the parsimonious specification of the cleared land equation presented above [equation (5')]; however, we wish to discuss briefly the alternative models that were estimated.

A. Specification Issues

1. The Logit v. the Linear Probability Model

Because the dependent variable in equation (5') is the ratio of cleared to total land, it is natural to consider transformations of the dependent variable that confine it to the interval (0,1). We estimated versions of the equation in which the dependent variable was the logit of (C/A), i.e., log[P/(1-P)], where P = C/A. We also tried the logarithm of P and the logarithm of its complement, 1-P. The choice of functional form is important because estimated elasticities of cleared land with respect to agricultural population and roads are somewhat sensitive to functional form. (See Appendix B.) For the reasons given below, we believe that the simple linear form in (5') is preferable to non-linear alternatives.

Our use of the linear probability model (i.e., P as the dependent variable) is motivated by two concerns. Use of ln P or ln (1-P) as the dependent variable leads to within-sample predictions of P that fall outside the (0,1) interval. This never occurs with the linear model. Second, the linear model is more robust with respect to changes in the set of explanatory variables than any of the other three models. In particular, the linear model is robust to changes in the instruments used for road density and population density. This is not true of the other three models.

We also experimented with alternative functional forms for the right-hand-side of the cleared land equation, trying logarithms of the variables as well as their linear forms. The difficulty with using the logarithms of road density and population density is that it is more difficult to find good instruments for these variables than for road density and population density per se.[5] This leads us to choose the parsimonious specification in (5').

2. Treatment of Agricultural Prices

If forest land is being cleared for agriculture, one would expect agricultural prices to explain at least some of the variation in percent of land cleared. The extent to which we can examine this is, however, limited by data on agricultural prices. Recall that the model is estimated for 58 provinces using data for 5 years. While we have information on the prices of rice, cassava, maize and rubber for the entire kingdom for each year, we have no information on the spatial variation in these prices. The best we can do is to interact these prices with regional dummies or with the distance of the province from Bangkok. Of the many variants of these models that were estimated, two are reported in Appendix C. They are typical of the results obtained: Prices (as measured) are almost never significant in explaining the fraction of land

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[5]Although the first-stage equations for ln (N/A) and ln (R/A) produce high R-squareds, individual coefficients are often statistically significant but of the wrong sign.

cleared. Alternative functional forms for agricultural household density, including $(N/A)^2$ and interactions between (N/A) and other variables (%Slope, %Soil), likewise proved unpromising.[6]

3. Models for Different Regions of Thailand

The final issue regarding model specification is whether to estimate separate models for different regions of Thailand. As the discussion in Section III suggests, the four regions of Thailand are heterogeneous in terms of climate, topography and the type of agriculture practiced. Forests in the North have often been replaced by rainfed rice and upland crops, whereas rubber and tropical fruits dominate in the South. Commercial agriculture plays a bigger role in the Central Plain than in the North of Thailand.

This suggests that separate models be estimated for each region; however, the small number of observations (approximately 70 for each region) makes this difficult. As a compromise, in addition to estimating a model for the entire kingdom using data for the years 1976, 1978, 1982, 1985 and 1989, separate models have been estimated for the North and Northeast combined, as well as for the South and Central Plain combined.[7] A model of the Northeast alone has been estimated using data for the years 1973, 1976, 1978 and 1982 to allow us to compare our results to those of Panayotou and Sungsuwan (1994).

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[6]In addition to estimating the structural model of equation (5'), we also experimented with a fixed effects model. Specifically, we estimated (5') with agricultural household density and road density replaced by instruments and with dummy variables added for each province. This, of course, necessitated dropping %Slope, %Soil Quality and Distance to Bangkok, which do not vary over time in the dataset. In the fixed effects model we failed to find a statistically significant impact of agricultural household density and road density on land clearing

[7]Time dummies for individual years are included in all models. Regional dummies are added to the model for the entire kingdom.

B. Empirical Results

1. Are Roads, Population Density and Cleared Land Jointly Determined?

Table 6 presents equation (5'), estimated via 2SLS using alternative sets of instrumental variables, for the entire kingdom. (OLS results are also presented for comparison.) Tables 7 and 8 show comparable results for the North/Northeast and Central Plain/South. Models for the Northeast alone appear in Table 9. Because of the poor results described above, agricultural price variables have been eliminated from all equations. Time dummies have been added, as have regional dummies to models for the entire kingdom.

In Tables 6, 8 and 9 the 2SLS and OLS models produce similar point estimates for most regression coefficients, although 2SLS coefficients are estimated with less precision. The similarity in estimates prompted us to test for the endogeneity of population density and road density using a Hausman test. For all tables (6 through 9) the null hypothesis cannot be rejected, suggesting that agricultural population density and road density can be treated as predetermined.[8] For this reason, we focus on the ordinary least squares results.

2. The Role of Agricultural Households and Roads in Explaining Land Clearing

When we examine the role of population pressures and roads in explaining land clearing in Thailand, two results stand out. One is that the relative importance of roads and population pressures differs markedly between the North and Northeastern regions of Thailand (hereafter referred to as the North) and the Southern region and Central Plain (hereafter referred to as the

[8]This is not due to our inability to find adequate instruments for agricultural population density and road density. As Appendix D reveals, we were able to explain a large portion of the variation in population density and road density in our first stage regressions. Moreover, all variables that are statistically significant have the expected sign.

Table 6: 2SLS and OLS Results for the Entire Kingdom, 1976-89
Dependent Variable: Proportion Cleared

(t-statistics in parenthesis)

Independent Variables	2SLS Results[1]	2SLS Results[2]	OLS Results	Elasticity of % of Cleared Land[3]	Elasticity of % of Forest Area[3]
Constant	0.614290* (6.704)	0.620454* (6.790)	0.625807* (12.172)		
Agricultural Household Density	0.006362 (1.332)	0.006825 (1.435)	0.008312* (3.495)	0.1147*	-0.2727*
Road Density	1.65337* (2.118)	1.57721** (2.030)	1.418245* (5.727)	0.2649*	-0.6298*
Percent Slope>30	-0.002640* -(6.165)	-0.00263* -(6.164)	-0.002573* -(6.952)	-0.1498*	0.3561*
Percent Acrisol	-0.000620 -(1.279)	-0.000597 -(1.233)	-0.000544 -(1.263)	-0.0609	0.1448
Distance to Bangkok	-0.0000762** -(2.148)	-0.0000754** -(2.127)	-0.0000751* -(2.234)	-0.0590*	0.1403*
1976 dummy	-0.011387 -(0.413)	-0.012805 -(0.465)	-0.013809 -(0.663)		
1978 dummy	0.009068 (0.407)	0.008568 (0.385)	0.009302 (0.464)		
1982 dummy	0.016456 (0.824)	0.16428 (0.824)	0.017612 (0.911)		
1985 dummy	0.007191 (0.376)	0.007267 (0.380)	0.008137 (0.430)		
Northern dummy	-0.101622* -(2.290)	-0.10536* -(2.383)	-0.114124* -(4.232)		
Northeastern dummy	0.006454 (0.149)	0.00292 (0.067)	-0.005851 -(0.207)		
Southern dummy	0.146941* (3.575)	0.144841* (3.531)	0.140737* (3.982)		
Central dummy	0.009780 (0.318)	0.007904 (0.258)	0.003197 (0.126)		
Adjusted R-squared	0.7408	0.7411	0.7556		
Number of Observations	290	290	290		

[1]Data is pooled for 1976, 1978, 1982, 1985, and 1989.

[2](instruments: non-agricultural GPP per capita, non-agricultural GPP per capita squared, total household density, total household density squared).

[3](instruments: non-agricultural GPP per capita, non-agricultural GPP per capita squared, total household density, total household density squared, distance*slope).

[4]Based on the OLS model.

* Statistically significant at 1-percent level ** Statistically significant at 5-percent level

Table 7: 2SLS and OLS Results for North and Northeast Combined, 1976-89
Dependent Variable: Proportion Cleared

(t-statistics in the parenthesis)

Independent Variables	2SLS Results[1]	OLS Results	Elasticity of % of Cleared Land[3]	Elasticity of % of Forest Area[3]
Constant	0.784626* (6.657)	0.715313* (7.471)		
Agricultural Household Density	0.027153* (2.548)	0.012125* (3.433)	0.2024*	-0.4053*
Road Density	-2.068481 -(1.227)	0.517009 (1.371)	0.0997	-0.1996
Percent Slope>30	-0.004215* -(7.908)	-0.004119* -(9.135)	-0.2205*	0.4415*
Percent Acrisol	0.001985 (1.409)	0.000491 (0.556)	-----	-----
Distance to Bangkok	-0.000243* -(3.757)	-0.000256* -(4.582)	-0.0534*	0.1069*
1976 dummy	-0.120042** -(2.064)	-0.043438 -(1.459)		
1978 dummy	-0.051796 -(1.197)	-0.004029 -(0.144)		
1982 dummy	-0.023618 -(0.641)	0.010394 (0.391)		
1985 dummy	-0.023618 -(0.641)	0.00343 (0.134)		
Adjusted Rsquared	0.7711	0.8171		
Number of Observations	160	160		

[1]Data is pooled for 1976, 1978, 1982, 1985, and 1989.

[2](instruments: non-agricultural GPP per capita , non-agricultural GPP per capita squared, total household density, total household density squared).

[3]Based on OLS model.

* Statistically significant at 1-percent level ** Statistically significant at 5-percent level

Table 8: 2SLS and OLS Results for South and Central Combined, 1976-89
Dependent Variable: Proportion Cleared

(t-statistics in the parenthesis)

Independent Variables	2SLS Results[1]	OLS Results	Elasticity of % of Cleared Land[2]	Elasticity of % of Forest Area[2]
Constant	0.555143* (6.820)	0.516694* (10.148)		
Agricultural Household Density	0.005335 (1.296)	0.007062* (2.520)	0.0752*	-0.2249*
Road Density	1.905286* (3.635)	2.015585* (7.399)	0.3632*	-1.0862*
Percent Slope>30	-0.001878* -(3.164)	-0.001601* -(3.569)	-0.1014*	0.3033*
Percent Acrisol	-0.000775 -(1.666)	-0.000865** -(2.041)	-0.0832**	0.2488**
Distance to Bangkok	0.0000738* (4.037)	0.0000709* (3.993)	0.0541*	-0.1618*
1976 dummy	-0.014062 -(0.488)	-0.004879 -(0.193)		
1978 dummy	-0.004202 -(0.155)	0.003247 (0.130)		
1982 dummy	0.000826 (0.032)	0.005402 (0.220)		
1985 dummy	0.003578 (0.147)	0.006342 (0.266)		
Adjusted Rsquared	0.5438	0.6476		
Number of Observations	130	130		

[1]Data is pooled for 1976, 1978, 1982, 1985, and 1989.
[2](*instruments: non-agricultural GPP per capita , non-agricultural GPP per capita squared, total household density, total household density squared, distance*slope*).
[3]Based on OLS results.
* Statistically significant at 1-percent level ** Statistically significant at 5-percent level

Table 9: 2SLS and OLS Results for Northeast Only, 1976-89 and 1973-82 Dependent Variable: Proportion Cleared

(t-statistics in the parenthesis)

Independent Variables	1976-89 2SLS Results[1]	1976-89 OLS Results	Elasticity of % of Cleared Land[2]	1973-82 2SLS Results[1]	1973-82 OLS Results	Elasticity of % of Cleared Land[2]
Constant	0.950948* (13.862)	0.902400* (15.468)		0.986150* (10.240)	0.950642* (10.174)	
Agricultural Household Density	0.012109* (3.658)	0.009903* (5.826)	0.1684*	0.013828** (1.871)	0.014284* (4.365)	0.2172*
Road Density	-0.335211 -(0.629)	0.196182 (1.191)	0.0347	-0.362958 -(0.295)	-0.210579 -(0.652)	-----
Percent Slope>30	-0.002270* -(6.361)	-0.002148* -(6.531)	-0.0272*	-0.002498* -(3.560)	-0.002372* -(4.339)	-0.0318*
Percent Acrisol	-0.002111* -(3.670)	-0.001948* -(3.694)	-0.2016*	-0.003306* -(3.624)	-0.003198* -(3.641)	-0.3502*
Distance to Bangkok	-0.00003423 -(0.464)	-0.000086** -(1.852)	-0.0534**	0.000096 (0.585)	0.000090 (1.072)	0.0591
1973 dummy	-----	-----		-0.135134* -(3.157)	-0.126074* -(5.500)	
1976 dummy	-0.054882** -(2.095)	-0.030421** -(1.856)		-0.061270* -(2.352)	-0.056099* -(2.786)	
1978 dummy	-0.001255 -(0.059)	0.016605 (1.093)		-0.010371 -(0.532)	-0.007791 -(0.407)	
1982 dummy	0.011731 (0.610)	0.26806** (1.920)		-----	-----	
1985 dummy	0.004127 (0.291)	0.009398 (0.736)		-----	-----	
Adjusted Rsquared	0.8423	0.8626		0.7990	0.8037	
Number of Observations	80	80		64	64	

[1]Data is pooled for 1976, 1978, 1982, 1985, and 1989 or for 1973, 1976, 1978 and 1982.
[2](instruments: non-agricultural GPP per capita , non-agricultural GPP per capita squared, total household density, total household density squared).
[3]Based on OLSmodel.
* Statistically significant at 1-percent level ** Statistically significant at 5-percent level.

South). The elasticity of percent of land cleared with respect to population density is three times higher in the North of Thailand than in the South. This accords with the fact that small farms and subsistence agriculture are far more important in the North than in the South. By contrast, roads have played a more important role in land clearing in the South than in the North. The elasticity of percent of land cleared with respect to road density is between 3 and 4 times higher in the South of Thailand than in the North.

The second result that deserves emphasis is that throughout Thailand, the elasticities of percent of land cleared with respect to population density and road density are well below one. The elasticity of percent cleared land with respect to agricultural population density is only 0.20 in the Northern part of Thailand and 0.075 in the South. The elasticity of the fraction of land cleared with respect to road density is 0.36 in the South-Central region and 0.10 in the Northeast-North.

We emphasize that these figures represent the elasticity of cleared land with respect to population or road density. Many estimates in the literature (including Panayotou and Sungsuwan) refer to the elasticity of forest land with respect to population or road density. To obtain the latter from the former in the linear case requires that we multiply the elasticity estimates in each table by the ratio of -P/(1-P).[9] This raises the absolute value of the elasticities considerably. The elasticity of forest-to-total-area with respect to population density is -0.41 for the North/Northeast section of the country and -0.22 for the South/Central region. The corresponding elasticities with respect to road density are -0.20 and -1.09.

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[9]Let denote the elasticity of P with respect to X and the elasticity of (1-P) with respect to X. Then = - P/(1-P).

To compare these elasticities with those of Panayotou and Sungsuwan, we estimated cleared land equations for the Northeast section of the country alone, using data for the same years as Panayotou and Sungsuwan (1973, 1976, 1978 and 1982). Our elasticity of forest area with respect to population density, -0.89, is much higher in absolute value than for the rest of the country, but still considerably below Panayotou and Sungsuwan's estimate of -1.50. The main reason why our results differ from those of Panayotou and Sungsuwan is very likely due to differences in our explanatory variables.[10] We were able to reproduce most of Panayotou and Sungsuwan's results using their model and our data. (See Appendix E.) In particular, Panayotou and Sungsuwan include per capita income, the price of wood, an agricultural price index and rice yield per rai as explanatory variables in their forest area equation. While the price variables can certainly be justified in explaining the percent of land cleared, per capita income and rice yield per rai would certainly seem to be jointly determined with the demand for cleared land.

3. The Role of Other Factors

Among the other factors that may explain agricultural clearing, topography, distance from Bangkok and, in some cases, soil quality are statistically significant. As in the case of population density and roads, the effect of these factors varies regionally.

In the North/Northeast, the fraction of land cleared is smaller the higher the percent of the province with slope greater than 30 degrees. This suggests that clearing is indeed more likely to

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[10]Using our explanatory variables and the same functional form as Panayotou and Sungsuwan (ln (1-P) on the natural logarithms of the explanatory variables), the elasticity of forest-to-total-area with respect to population density is 0.73, still considerably lower (in absolute value) than Panayotou and Sungsuwan's estimate.

occur in valleys than on hills, due, no doubt, to clearing costs. It may also reflect the better soil quality and lower risk of soil erosion in lowland areas than on upland slopes. The fraction of land cleared is also smaller the farther the province is from Bangkok. This may occur because distance from Bangkok captures transport costs; hence, the net returns from export crops are smaller the farther a province is from Bangkok.

The soil variable measures the percent of the province with acrisol soil. Acrisol soils are very easily eroded, which imposes limitations on their use for agriculture. It is thus likely that the demand for clearing would be less in areas where soil is predominantly acrisol, rather than fluvisol or gleysol.[11] Soil quality, while of the correct sign, is not statistically significant in explaining the fraction of land cleared when the North and Northeast provinces are combined; however, it is significant in the Northeast.

In the South and Central Plain, Slope and Soil Quality are significant and have the expected signs; however, Slope has a smaller impact and Soil Quality a large impact than in the North. The one anomaly in the model of Table 8 is the effect of Distance from Bangkok on the fraction of the province cleared. In the South and Central Plain the fraction of the province cleared increases with Distance from Bangkok. This is very likely due to the fact that most provinces close to Bangkok were excluded from the sample. As noted above, we included in this analysis only those provinces in our analysis with some forest area remaining in 1973. Most provinces near Bangkok had been completely cleared by 1973; hence, they were excluded from

[11] Fluvisol, Gleysols and Acrisols are the most common of the 26 FAO/Unesco soils classes found in Thailand. Fluvisols and Gleysols are more fertile classes used for dryland crops and paddy rice. Acrisol is a less fertile class, usually requiring shifting cultivation with adequate fallow periods for sustainable use.

the sample. Had they been included, the coefficient of distance would likely be negative.

Two other results of interest pertain to the time and regional dummy variables. It is clear from Tables 6 through 8 that none of the time dummies is statistically significant, implying that the nature of land market equilibrium did not change over the period studied. Regional dummies are, however, significant in Table 6 for the Northern provinces and for the South,[12] which support the estimation of the disaggregated models in Tables 7 and 8.

C. Quantitative Implications of Our Findings

To make the implications of our model more meaningful, we use the model to make out-of-sample predictions of the percent of land cleared, both for the country as a whole and for one province, Mae Hong Song.

When the model of Table 6 is used to predict the percent of land cleared in 1991, the average prediction error for the 58 provinces in our sample is 10%. Based on Tables 7 and 8 the prediction error for North and Northeast regions combined is 12%; it is 8% for the South and Central regions combined.

When the model of Table 7 is used to predict the impact of changes in agricultural population density on deforestation in Mae Hong Song, the predicted impacts are relatively modest.[13] These estimates imply that in Mae Hong Song, which had 72% of its area (9,130 sq.

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[12]They suggest that, for the Northern provinces, unobserved factors would cause us to predict a ten percentage point lower level of clearing than we would predict in the Central/Eastern region of the country. In the South, by contrast, unobserved factors would cause us to predict a 14 percentage point higher level of clearing than we would predict in the Central/Eastern region of the country.

[13]The prediction error for Mae Hong Song is 9 percent.

km.) under forest cover in 1991, an increase in agricultural household density from 1.8 households per sq. km. to 6.8 households per sq. km. would result in only 524 sq. km. of deforestation. The effect of increasing road density from 0.06 km. of roads per sq. km. to 0.10 km of roads per sq. km. would be to deforest 703 sq. km. of the province. The elasticity estimates thus suggest that in terms of the magnitude, the impact of population density and road development on land clearing are small. They clearly do not support the findings of earlier studies on Thailand that had predicted elasticities of population density over 1. It is unlikely that swidden cultivation practiced especially in North and Northeast would have led to clearing of the magnitude suggested by these studies.

V. CONCLUSIONS

The perspective taken in this paper is that, in the long run, the determinants of deforestation are the determinants of land use change. While logging and fuelwood gathering may remove forest cover, regrowth will occur, at least in moist tropical forests. For an area to remain deforested, it must be profitable to convert the land to another use, and this use is usually agriculture. This paper thus focuses on what, in equilibrium, determines the amount of land cleared for agriculture, and attempts to quantify the magnitude of these effects.

The profitability of clearing land for agriculture depends on the physical properties of land, including topography and soil quality, as well as upon access to markets. With regard to physical factors, our analysis suggests that steep slopes and poor soil quality provide some natural protection to forests, although the quantitative impacts of these factors differ between the North/Northeast of Thailand and the South/Central region. To illustrate, imagine two provinces, exactly the same in all respects except that the second province has 10% more of its land area with a slope greater than 30%. In the North, we would expect the second province to have 4.4% more forest cover (forest to total area) than the first due to the fact that more steeply sloped areas are harder to clear. In the South, the second province would have only 3% more forest area. Topography has thus provided forests with more protection in the North than in the South.

Poor soil quality, on the other hand, has reduced the rate of land clearing more in the South than in the North. Suppose one province in the South has 10% more land containing acrisol soil than a second province. The first province, according to our model, will have 2.5% more forest cover than the second. In the North, by contrast, differences in the percent of acrisol soil have no statistically significant impact on the fraction of the province cleared.

Differences in the impact of topography and soil quality between the North and South of Thailand very likely reflect differences in nature of agriculture in the two regions. Commercial agriculture plays a much more important role in the South than in the North, and this may account for the greater importance of soil quality. It also likely explains the greater impact of roads on land clearing in the South than in the North. Our analyses suggest that, in South and Central Thailand, a 10% increase in road density over the period of the study reduced forest cover by almost 11%. By contrast, in the North and Northeast a 10% increase in road density reduced forest cover by only 2%.

Total area cleared is determined not only by the inherent profitability of clearing, but by the number of households demanding agricultural land. According to our estimates, the effect of population pressures has been stronger in the North than in the South. Over the period of our study, a 10% increase in agricultural households in the North was responsible for a 4% decrease in forest area. In the South, this same increase caused only a 2.3% reduction in forest area.

While our estimates of the impact of roads and population growth on deforestation may seem modest by contrast to other studies, the two factors together explain about 70% of the deforestation that occurred in Thailand between 1976 and 1989. During the period of our study about 1.2 million new agricultural households and about 17,000 km of roads were added in the North and Northeast of the country. Our analysis suggests that these two factors caused the clearing of 16,000 km^2 and 9,000 km^2 of new land respectively. In the South and Central regions, approximately 550,000 new agricultural households and 4,700 km of new roads caused 4,000 km^2 and 8,800 km^2 newly cleared land. The total amount of cleared land, approximately 55,000 km^2, accounts for 69% of the total forest area lost during the period. We expect that the remainder of clearing can be explained in part by changes in agricultural prices during the period, but cannot test this hypothesis without spatially disaggregated data on agricultural prices.

APPENDIX A: DESCRIPTION OF THE DATA

A. Cleared Land

The dependent variable in the model is fraction of the province cleared, but this data is not published. The data for cleared land for each province is therefore assumed to be any area that is non-forested and is calculated by subtracting the forested area from the total area of the province. Information on forest area (in square kilometers) comes from remote sensing data published by the Royal Forestry Department. It is available by region and by province for the years 1973, 1976, 1978, 1982, 1985, 1989, and 1991.

Unfortunately, the data published by the Thai government do not contain an exact definition of forest cover. Since it is difficult to distinguish individual forest type without ground truthing[1], we assume that forest area means any type of woody ground cover. This is consistent with the United Nations Food and Agriculture Organization's (FAO's) definition for forest area which includes both closed and open forest and plantations. This is a very broad classification of forest area available but is useful when analyzing forests from an economic perspective.

B. Agricultural Population

Population data were obtained from the National Statistical Office in the Office of the Prime Minister. This office publishes a detailed population and housing census survey once every ten years. The surveys give a detailed account of demographic and socio-economic characteristics of the population as well as housing conditions. Agricultural households data were

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[1]Ground truthing implies verification of the satellite pictures of forests using aerial surveys (usually done using helicopters).

obtained for each province for 1970, 1980, 1990, and were linearly interpolated for the intervening years.

C. Road Data and Distance to Bangkok

The road data were obtained by digitizing the 1970, 1973, 1978, 1982, 1987, 1989 and 1991 road maps from the Department of Highways. This was done by first digitizing the paved roads, unpaved roads and railroads from the 1978 road map using Arclnfo. This digitization was then imported into Atlas GIS and checked for errors. The provincial boundaries were obtained from the Digital Chart of the World and were used to allocate roads to their respective province. The 1978 map was then revised in Atlas GIS to reflect the changes of the other years.[2]

The variable distance to the Bangkok metropolis comes from the Department of Highways publications. It is not stated how this figure was calculated, but it probably from the central point of each province using the most direct route. It is not known, however, if this distance represents on-the-ground travel distance or some type of straight line estimation. We chose to use this official figure rather than that given from our road map due to potential inaccuracies in the road map.

D. Geophysical Data

The soil quality data were extracted from FAO's digitized 1974 soil map of the world at a scale of 1-5,000,000.[3] This map identifies 129 categories of soil type, fifteen of were found in Thailand. They were collapsed into three broad categories: Fluvisol, Gleysol and Acrisol.

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[2]Thanks to Donna Schaller who meticulously did all of the digitization and error-checking.

[3]The map was extracted at a resolution of two minutes square.

Fluvisols are very productive for a wide range of dryland crops and for paddy rice on flood plains, river levees or terraces. Gleysols are almost as productive as but their agricultural potential depends on the flooding regime and on the possibility of drainage. Acrisols are very easily eroded, which imposes severe limitations on their agricultural potential. The percentage of each soil type in each province has been calculated.

The slope data are derived from the digital elevation map from the U.S. National Geophysical data center in Colorado. They consist of elevation readings sampled every five-minutes (approximately nine square kilometers) with a one-meter contour interval. The slope ranges were collapsed into three broad categories: a slope of 0°, a slope between 0° and 10°, and a slope over 30°. We have calculated the percentage of the provincial area in each category. For the regressions, we took the percentage of the province that included classifications with a slope of greater than 30°.

E. The National Income Data

The National Income data come from the *National Income of Thailand*, issued by the Office of the National Economic and Social Development Board in the Office of the Prime Minister. Tables from this publication are cited in the *National Statistical Yearbooks*. The Gross Provincial Product for all the provinces is available for the years 1975-1988. Data by sector (e.g., agriculture and non-agriculture), however, is available at the provincial level only for years 1981-1989. We first verified that the sector totals summed to the gross provincial product for the years in which both were available. We then estimated agricultural and non-agricultural gross provincial products for the 1975-1980 using regression analysis.

F. Price Data

The price data for different agricultural commodities such as rice, cassava, maize and rubber are published in the *Statistical Yearbooks*. They contain annual data for the entire Kingdom for the years 1971-1990.

APPENDIX B: ALTERNATIVE SPECIFICATIONS OF THE DEPENDENT VARIABLE

Table B below lists the elasticity of cleared area to total area (C/A) with respect to key explanatory variables based on different specifications of the dependent variable in the cleared land equation. Define P as the ratio of cleared to total area. The four specifications estimated are as follows: the linear probability model (P as the dependent variable), the logit model (using log(P/1-P)), the log-linear model (using log(P)), and the log-linear form using P's compliment (that is, log(1-P) as the dependent variable). As can be seen, elasticities are generally higher in absolute value in all of the other model than in the linear model. The exceptions are a lower elasticity for % Slope in the logit and the log(1-P) models, for Acrisol in the log(P) form, and for Distance to Bangkok in the log(1-P) model. This suggests that the amount of land clearing that we can attribute to each of these causes will be different under different specifications. In the end, our choice of the linear specification was driven by the accuracy of within-sample predictions and robustness to changes in the independent variables and instruments.

Table B: Elasticities of (C/A) Under Alternative Specifications

	p	log (p/1-p)	log(p)	log(1-p)
Agricultural Household Density	0.1147	0.1846	0.1229	0.2106
Road Density	0.2649	0.3733	0.3353	0.3893
Percent Slope>30	-0.1497	-0.1367	-0.1945	-0.1123
Percent Acrisol	-0.0609	-0.2180	-0.0117	-0.3048
Distance to Bangkok	-0.0590	-0.0709	-0.1193	-0.0504

APPENDIX C: OLS AND 2SLS RESULTS USING AGRICULTURAL PRICES

Table C below shows the results of two alternative specification of equation (5') incorporating agricultural prices. One would expect agricultural prices to affect the amount of land cleared, but we are limited in our ability to test this because of the lack of spatially disaggregate prices. We have information on the price of rice, cassava, maize and other agricultural products over time, but no information on how these prices vary by province. The best that we can do is to interact these prices with either regional dummies or the distance of the province to Bangkok. For both of these models, we have run an ordinary least squares and a 2-stage least squares regression.

The first two columns of Table C show the results of interacting the price of rice, Thailand's primary agricultural product, with regional dummies. The coefficients of the main explanatory variables maintain the same sign, significance and magnitude as the model without agricultural prices, and the interacted price terms are insignificant. The last two columns show the results of dividing the price of rice by the distance to Bangkok. The idea is that the farmgate price declines as the distance to this major market declines. Again, the primary exogenous variables are roughly the same and the price term is insignificant.

Table C: OLS and 2SLS Results with Agricultural Prices
Dependent Variable: Percent Cleared
Pooled (1976, 1978, 1982, 1985, 1989)

(t-statistics in parenthesis)

Independent Variables	OLS Results	2SLS Results[1]	OLS Results	2SLSResults[1]
Constant	0.629519* (11.361)	0.622223* (6.918)	0.702075* (9.855)	0.660186* (6.629)
Agricultural Household Density	0.008596* (3.597)	0.006607 (1.438)	0.008306* (3.501)	0.005648 (1.279)
Road Density	1.442421* (5.775)	1.660214** (2.209)	1.382496* (5.572)	1.816* (2.811)
Percent Slope>30	-0.002525* -(6.790)	-0.002608* -(6.050)	-0.002727* -(7.130)	-0.002731* -(6.258)
Percent Acrisol	-0.000547 -(1.269)	-0.000620 -(1.289)	-0.000633 -(1.461)	-0.000757 -(1.622)
Distance to Bangkok	-0.0000766* -(2.272)	-0.000077* -(2.171)	-0.00009* -(2.673)	-0.0001* -(2.689)
1976 dummy	-0.037873 -(0.731)	-0.037951 -(0.717)	-0.025398 -(1.150)	-0.016366 -(0.604)
1978 dummy	0.004391 (0.189)	0.003142 (0.127)	0.005781 (0.287)	0.008829 (0.405)
1982 dummy	0.007118 (0.249)	0.004890 (0.169)	0.012616 (0.645)	0.013180 (0.652)
1985 dummy	-0.006541 -(0.194)	-0.008620 -(0.253)	0.001987 (0.103)	0.002114 (0.108)
Northern dummy	-0.138964 -(1.064)	-0.121022 -(0.863)	-0.137572* -(4.452)	-0.11396* -(2.555)
Northeastern dummy	0.127565 (0.970)	0.145578 (0.992)	-0.036361 -(1.057)	-0.013132 -(0.281)
Southern dummy	0.238968** (1.729)	0.244424** (1.729)	0.121501* (3.249)	0.135275* (3.200)
Central dummy	0.039155 (0.258)	0.046193 (0.302)	0.000556 (0.022)	0.011500 (0.391)
Northern dummy * Rice Price	0.000004 (0.199)	0.000003 (0.150)	-----	-----
Northeastern dummy * Rice Price	-0.000022 -(1.044)	-0.000023 -(1.052)	-----	-----
Southern dummy * Rice Price	-0.000016 -(0.729)	-0.000016 -(0.725)	------	------
Central dummy * Rice Price	-0.000006 -(0.240)	-0.000006 -(0.244)	------	------
Rice Price/Distance to Bangkok	------	------	-0.001125 -(1.543)	-0.001014 -(1.347)
Adjusted R-squared	0.7547	0.7395	0.7568	0.7435
Number of Observations	290	290	290	290

[1](instruments: non-agricultural GPP per capita, non-agricultural GPP per capita squared, total household density, total household density squared)

* Statistically significant at 1-percent level ** Statistically significant at 5-percent level

APPENDIX D: AGRICULTURAL HOUSEHOLD AND ROAD DENSITY EQUATIONS

Table D below gives the first stage of the two-stage least squares regressions of agricultural household density and road density, as specified by equations (6') and (7'). Two versions are estimated. In the first, the instruments are total household density, total household density squared, per capita non-agricultural Gross Provincial Product (GPP), and per capita non-agricultural Gross Provincial Product squared. In the second specification, the product of distance to Bangkok and percentage of land area with a slope > 30% is also included as an instrument. Total household density reflects population pressure and should affect both equations positively. Non-agricultural GPP per capita reflects off-farm income opportunities so it should affect agricultural household density negatively. How non-agricultural GPP should affect road density is indeterminate. The product of % slope * distance to Bangkok captures the idea that physical factors are a greater barrier to road building in more remote provinces.

Table D: Agricultural Household and Road Density Equations
First Stage (OLS) Results
Pooled (1976, 1978, 1982, 1985, 1989)

(t-statistics in parenthesis)

Dependent Variable	Agricultural Household Density	Agricultural Household Density	Road Density	Road Density
Constant	0.481303 (0.334)	0.367415 (0.251)	0.070221* (3.893)	0.070967* (3.869)
Total Household Density	0.814330* (11.322)	0.812334* (11.257)	0.004348* (4.828)	0.004361* (4.825)
Total Household Density squared	-0.010602* -(6.147)	-0.010549* -(6.093)	-0.0000544* -(2.521)	-0.000054* -(2.527)
Non-Agricultural GPP per capita	-0.022526** -(2.146)	-0.021971** -(2.076)	0.000074303 (0.565)	0.0000706 (0.533)
Non-Agricultural GPP per capita squared	0.00001837 (0.510)	0.000017404 (0.482)	0.00000036 (0.803)	0.000000368 (0.814)
Distance to Bangkok * Slope	-----	-0.00000850 -(0.454)	-----	5.5694E-08 (0.237)
Percent Slope>30	-0.034169* -(4.489)	-0.030269* -(2.636)	-0.000220** -(2.309)	-0.000246** -(1.708)
Percent Acrisol	0.016438** (1.833)	0.015482 (1.678)	0.000353* (3.144)	0.000359* (3.110)
Distance to Bangkok	-0.001265** -(1.724)	-0.000795 -(0.626)	0.0000120 (1.314)	0.000008998 (0.566)
1976 dummy	-1.681033* -(3.268)	-1.663598* -(3.221)	-0.021697* -(3.369)	-0.021811* -(3.372)
1978 dummy	-1.534130* -(3.262)	-1.520856* -(3.223)	-0.010586** -(1.798)	-0.010673** -(1.806)
1982 dummy	-0.999727* -(2.403)	-0.994943* -(2.388)	-(0.006191) -(1.189)	-0.006222 -(1.192)
1985 dummy	-0.708608** -(1.782)	-0.705212** -(1.770)	-0.002114 -(0.425)	-0.002137 -(0.428)
Northern dummy	2.391575* (4.183)	2.387474* (4.170)	-0.022810* -(3.187)	-0.022784* -(3.177)
Northeastern dummy	3.721377* (5.965)	3.673575* (5.798)	-0.010459 -(1.339)	-0.010146 -(1.279)
Southern dummy	1.446789** (1.955)	1.411948** (1.895)	-0.014787 -(1.596)	-0.014559 -(1.561)
Central dummy	-0.925438 -(1.608)	-0.938629 -(1.626)	-(0.018049)* -(2.505)	-0.017963* -(2.485)
Number of Observations	290	290	290	290
Adjusted R-squared	0.8200	0.8195	0.5437	0.5422

* Statistically significant at 1-percent level ** Statistically significant at 5-percent level

APPENDIX E: REPLICATION OF RESULTS BY PANAYOTOU AND SUNGSUWAN

In an influential study, Panayotou and Sungsuwan (1994) model the natural logarithm of forest area to total area as a function of the logarithm of population density, road density, Gross Provincial Product per capita, wood price, an agricultural price index, the distance to Bangkok, the rice yield per rai, and the amount of irrigation infrastructure. They predict an elasticity of forest-to-total-area with respect to population density of -1.5. The results of our study suggest an elasticity much lower than this. When equation (5') was estimated for the same area and the same years an elasticity of only -0.89 was obtained. Table E below attempts to estimate the same model as Panayotou and Sungsuwan using the data from this study. We were, however, unable to find measures of spatially disaggregate agricultural prices and irrigation infrastructure. As can be seen, we were able to produce results very similar to Panayotou and Sungsuwan's study. It should be noted that the elasticity of forest-to-total area with respect to population density in our estimation is only -0.73, considerably lower then Panayotou and Sungsuwan's estimate.

Table E: Panayotou Comparison (Northeast Only)
(Dependent Variable: log(Forest Area/Total Area))
Pooled (1973,1976, 1978, 1982)

(t-statistics in parenthesis)

Independent Variables	Original Panayotou Model	Panayotou Model Using Our Data[1]
Constant		-1.805 -(0.67)
log Population Density	-1.51* -(9.7)	-0.997* -(5.19)
log Road Density	-0.11 -(1.4)	-0.598** -(2.22)
log GPP Per Capita	0.42* (4.0)	0.544** (1.94)
log Wood Price	-0.41* -(4.1)	-0.546* -(2.81)
log Agricultural Price Index	-0.32 -(1.7)	---
log Distance to Bangkok	0.70* (4.8)	-0.218 -(0.77)
log Rice Yield Per Rai	0.38** (1.9)	0.218 (1.32)
log Irrigation Infrastructure	-0.02 (-1.02)	---
Adjusted R-squared	0.77	0.62
Number of Observations	64	64

1. Since we could not obtain data on all the Panayotou variables they are not reported.
* Statistically significant at 1-percent level** Statistically significant at 5-percent level.

REFERENCES

Binswanger, Hans and Prabhu Pingali (1984), "Population Density and Agricultural Intensity: A Study of the Evolution of Technology in Tropical Agriculture," The World Bank.

Chomitz, Kenneth M. and David P. Gray (1996), "Roads, Land, Markets and Deforestation: A Spatial Model of Land Use in Belize," The World Bank Economic Review, Vol. 10, no. 3, pp. 487-512.

Feder, Gershon, Tongraj Onchan, Yongyuth Chalamwong and Chira Hongladarom (1988), "Land Policies and Farm Productivities in Thailand," The Johns Hopkins University Press, Baltimore.

Feeny, David (1984), "Agricultural Expansion and Forest Depletion in Thailand, 1900-1975," QSEP Research Report, McMaster University (Canada), No. 108, pp. 1-65.

Mahar, Dennis J. (1989), "Government Policies and Deforestation in Brazil's Amazon Region," The World Bank.

Panayotou, Theodore (1991), "Population Change and Land Use in Developing Countries: The Case of Thailand," HIID Working Paper, Cambridge, Massachusetts.

Panayotou, Theodore and Somthavin Sungsuwan (1989), "An Econometric Study of the Causes of Tropical Deforestation: The Case of Northeast Thailand," Development Discussion Paper No. 284, HIID, Cambridge, Massachusetts.

Pfaff, Alexander S. (1994), "What Drives Deforestation in the Brazilian Amazon," Mimeo, MIT, Cambridge, Massachusetts.

Reis, Eustaquio and Sergio Margulis (1991), "Options for Slowing Amazon Jungle Clearing," in Dornbusch, R. and Poterba, J. (eds.) Global Warming: The Economic Policy Responses, MIT Press, Cambridge, Massachusetts.

Southgate, Douglas, Rodrigo Sierra, and Lawrence Brown (1991), "The Causes of Tropical Deforestation in Ecuador: A Statistical Analysis," World Development, vol. 19, no. 9, pp. 1145-1151.

Stavins, Robert N. and Adam B. Jaffe (1990), "Unintended Impacts of Public Investments on Private Decisions: The Depletion of Forested Wetland," The American Economic Review, Vol. 80, No. 3, pp. 337-352.

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