# Roads, Population Pressures, and Deforestation in Thailand, 1976–1989

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ABSTRACT. *We estimate an equilibrium model of land clearing to study the impacts of roads and population on deforestation in Thailand between 1976 and 1989. Population pressures were more important in the North and Northeast sections of Thailand (elasticity of forest area with respect to agricultural population density = −0.82) than in the South and Central regions (elasticity = −0.46). Road building was more important in the South/Central region than in the rest of the country. The elasticity of forest area with respect to road density is −1.5 in the South/Central region, but is not statistically significant in the North/ Northeast.* (JEL Q23)

## I. INTRODUCTION

Tropical deforestation is considered to be one of the major environmental disasters of the twentieth century, yet there have been few careful studies of its causes.[1] 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 between 1961 and 1988. During the same period, forest land decreased by 13.6 million hectares. 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 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 1997; 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 1996). 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 1970s. The purpose was to assist the military in their efforts to secure the area against communist encroachment from Laos (Caldwell 1974;

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[1] A notable exception is the recent volume by Brown and Pearce (1994).

Muscat 1990). Road building very likely spurred deforestation in the Northeast during the 1970s and 1980s; 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 important, 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 Northern region 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, 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. As population density increases, however, the length of the fallow period typically decreases and shifting cultivation becomes less profitable. This may lead, as noted by Boserup (1965) and Binswanger and Pingali (1984), to more intensive farming practices, 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, and 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, and with the price of timber.

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: While population pressures are a statistically significant determinant of land clearing for Thailand as a whole, we find that they played a much greater role in land clearing the North

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

and Northeast sections than in the South and Central regions. The elasticity of forest area with respect to agricultural population density is $-0.82$ in the North and Northeast sections combined, but only $-0.46$ in the South/Central regions. In the Northeast, due to the low initial forest stock, the elasticity of forest area with respect to agricultural population density is well above one in absolute value, a finding that agrees with Panayotou and Sungsuwan (1994).

Road building, by contrast, appears to have been much more important in promoting land clearing the South and Central regions of Thailand than in the rest of the country. The elasticity of forest area with respect to road density is $-1.5$ in the South/Central region, a result consistent with the largely commercial nature of agriculture in this region. Although road density is not statistically significant in the North and Northeast, our measure of roads cannot distinguish their location. The importance of timber prices in explaining land clearing in the North and Northeast—both directly and through their impact on the number of agricultural households—suggests that logging roads may indeed have played a role in deforestation of this region.

The paper is organized as follows: Section 2 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. Our empirical results are presented in Section 3, and our conclusions in Section 4.

## 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 is 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 1996).

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 Jaffe 1990) or the fraction of a county converted from forest to agriculture (Pfaff 1997).

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 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 the 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 equa-

[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).

tions 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 ($L_C$) is a function of its rental price ($p_C$), the cost of labor ($l$) and capital ($k$), the price of agricultural output ($p_A$) and factors that affect the productivity of land for agriculture, such as soil quality ($Q$) and slope ($s$). The farmer's static profit maximizing problem is given by:

$$\underset{(l,k,L_C)}{\text{MAX}}\ \Pi = (p_A - t)\cdot y(l, k, L_C, Q, s) - wl - rk - p_C L_C \qquad [1]$$

where $t$ represents transport costs, $y$ is the production function for agricultural output, $w$ is the wage rate, and $r$ is the rental rate on capital.

Solving the first-order conditions to equation [1] yields a demand function for cleared land,

$$L_C = f(p_A, t, w, r, p_C, Q, s) \qquad [2]$$

which depends on the price of agricultural output, transport costs, the wage rate, the rental rate of capital, the rent on agricultural land, soil quality and slope. To derive the aggregate demand for cleared land in the county, $C^D$, we multiply equation [2] by $N$, the number of agricultural households in the county,[4]

$$C^D = NL_C\,(p_A, t, w, r, p_C, Q, s) \qquad [3]$$

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. The cost of clearing is reduced by any revenues received from the sale of timber; hence the cost of clearing should vary inversely with the price of logs, $p_L$. 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

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

where $C^S$ is the supply of cleared land and $R$ represents the length of the road network.

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 the rental price of land. If land rent 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, the price of logs, and the slope of land. The cleared land equation is thus given by

$$C = C(N, t, Q, p_A, w, r, R, p_L, s) \qquad [5]$$

In equation [5] it is possible that agricultural population ($N$) and roads ($R$) are determined simultaneously with land use; hence

[4] The fact that the number of agricultural households is determined simultaneously with cleared land is discussed explicitly below.

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).[5]

The number of agricultural households in a province can be written as the product of the number of households in the province ($T$) 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 ($T$), roads ($R$), cleared land ($C$), soil quality ($Q$), slope ($s$), agricultural prices ($p_A$) and non-agricultural Gross Provincial Product,

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

*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, earthmoving equipment and materials) as well as on physiographic factors. As Chomitz and Gray (1996) 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. We also hypothesize that the road network will be more dense the closer the province is to the capital.

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

$$R = h(T, d, s, C, \text{GPP}) \qquad [7]$$

where $d$ represents distance to Bangkok.

*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

[5] This interpretation of the agricultural population equation should not be taken too literally. Some members of the household may work in agriculture and others outside of the sector. It is also the case that household members who work in agriculture may migrate to find wage work during the dry season. It is still the case that non-agricultural GPP will proxy opportunities outside of agriculture.

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.[6] This implies that the dependent variables are now proportion of the province cleared, agricultural household density, and road density. Likewise, slope and soils are now the proportion of each province in particular slope and soil quality categories.

For purposes of estimation, the simplest forms of equations [5], [6], and [7] are the linear versions of these equations. In the cleared land equation estimated below the wage and the rental rate of capital have been dropped, since these variables are not available at the provincial level. The price of agricultural commodities is measured by the price of rice, since rice accounts for 60–70% of the acreage planted during the period of the study. In the case of both the price of rice and the price of logs, provincial price equals national price minus transport cost. Since our equation is linear in form, we enter the national price and transport cost separately. 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. The cleared land equation becomes:

$$
\begin{aligned}
(C/A)_{it} = {} & \alpha_0 + \alpha_1(N/A)_{it} + \alpha_2(R/A)_{it} \\
& + \alpha_3 p_{Ait} + \alpha_4 \text{ Distance}_i \\
& + \alpha_5 p_{Lit} + \alpha_6(\%\text{Soil})_i \\
& + \alpha_7(\%\text{Slope})_i + \xi_{it}
\end{aligned}
\qquad [5']
$$

The cleared land equation is exactly identified provided that non-agricultural GPP and total population appear in the agricultural population and road equations but not in the cleared land equation. In estimating [5′] we used non-agricultural population rather than total population as an instrument, since the latter by definition includes agricultural households. A question of interest is how sensitive the estimated coefficients are to the choice of instrumental variables. To explore this, we estimated variants of the model that included the squares of non-agricultural GPP and non-agricultural households as instruments, as well as the product of % Slope and Distance from Bangkok. The latter variable could be added to the road equation to capture the notion that physical barriers are more of an obstacle to road building the more remote the province.

*E. Estimation of the Model*

The model was 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 was 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 the Appendix.)

## III. EMPIRICAL ANALYSIS

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

*A. Specification Issues*

*1. The logit vs. 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 ($C/A$), that is, $\log[P/(1 - P)]$, 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

[6] As a referee pointed out, it might make more sense to divide by the amount of usable land which, in mountainous areas, is less than the total land available. This would be especially important in the North of Thailand. Due to the difficulty in defining "usable," we maintain the convention of dividing variables by the total area of each province.

with respect to agricultural population and roads are somewhat sensitive to functional form. (See Cropper, Griffiths, and Mani, 1997). 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.[7] This led us to choose the parsimonious specification in [5′].

*2. Models for different regions of Thailand.* The second issue regarding model specification is whether to estimate separate models for different regions of Thailand. Thailand is comprised of four regions (see Figure 1): the North, Northeast, Central Plain and South.[8] The regions are heterogeneous in terms of climate, topography, and the type of agriculture practiced. Forests in the North and Northeast 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 South and Central Plain than in the North and Northeast 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. A model of the Northeast alone has been estimated to allow us to compare our results to those of Panayotou and Sungsuwan (1994).

*B. Empirical Results*

*1. The role of agricultural households in explaining land clearing.* Table 1 presents equation [5′], estimated for the entire kingdom via 2SLS using the most complete set of instrumental variables.[9] (OLS results are also presented for comparison.) Tables 2 and 3 show comparable results for the North/Northeast and Central Plain/South. Models for the Northeast alone appear in Table 4. Regional dummies have been added to models for the entire kingdom.

When we examine the role of population pressures in explaining land clearing in Thailand, two results stand out. One is that the relative importance of 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 South). The elasticity of proportion of land cleared with respect to population density is over twice as high in the North of Thailand as it is 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.

The second result that deserves emphasis is that throughout Thailand, the elasticities of percent of land cleared with respect to population density are well below one. The elasticity of percent cleared land with respect to agricultural population density is only 0.41 in the North of Thailand and 0.15 in the South.

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[7] 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.

[8] Our definition of the four regions follows the Thailand *National Statistical Yearbooks*.

[9] This includes non-agricultural GPP per capita, (non-agricultural GPP per capita)$^2$, non-agricultural households, (non-agricultural households)$^2$, (distance to Bangkok) × (%Slope)/(%Slope >30). When the test of over-identifying restrictions was applied to various sets of instruments, this set performed the best.

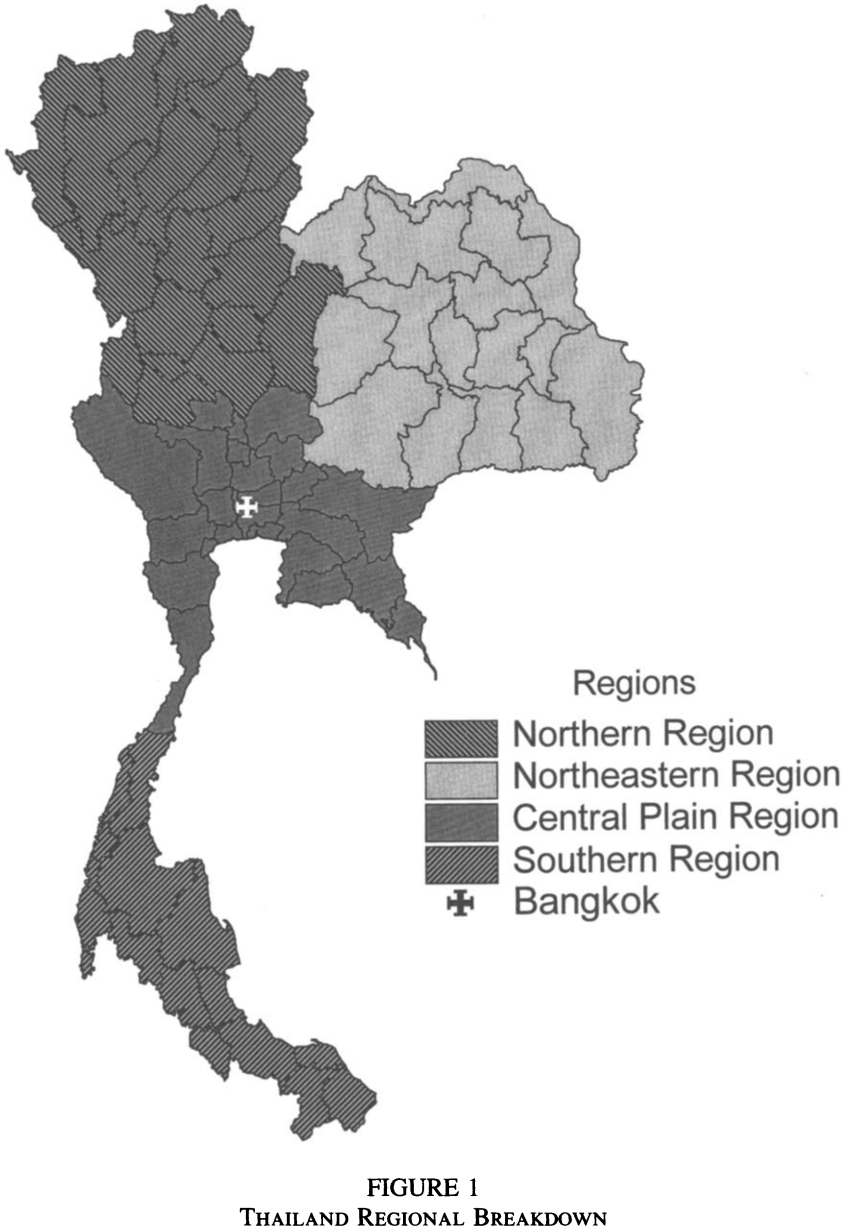


FIGURE 1
THAILAND REGIONAL BREAKDOWN

We emphasize that these figures represent the elasticity of *cleared land* with respect to population. Many estimates in the literature (including Panayotou and Sungsuwan (1994)) 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 $-P/(1 - P)$.[10] This raises the absolute value of the elasticities considerably. The elasticity of forest-to-total area with respect to popula-

[10] Let $\epsilon$ denote the elasticity of $P$ with respect to $X$ and $\eta$ the elasticity of $(1 - P)$ with respect to $X$. Then $\eta = -\epsilon P/(1 - P)$.

TABLE 1

2SLS AND OLS RESULTS FOR THE ENTIRE KINGDOM, 1976–1989

Dependent Variable: Proportion Cleared

| Independent Variables | 2SLS Results[a] | OLS Results | Elasticity of % of Land Cleared[b] | Elasticity of % of Land Under Forest Cover[b] |
|---|---|---|---|---|
| Constant | 0.502953** | 0.558748** | | |
| | (4.169) | (4.919) | | |
| Agricultural household density | 0.009981 | 0.007815** | 0.1377 | −0.3275 |
| | (1.802) | (3.326) | | |
| Road density | 2.283935** | 1.485713** | 0.4266** | −1.0143** |
| | (3.195) | (6.130) | | |
| Percent slope >30 | −0.001816** | −0.002585** | −0.1057** | 0.2512** |
| | −(3.397) | −(7.034) | | |
| Percent acrisol | −0.000751 | −0.000565 | | |
| | −(1.526) | −(1.312) | | |
| Distance to Bangkok | −0.000103** | −0.000075* | −0.0808** | 0.1921** |
| | −(2.790) | −(2.248) | | |
| Log price | −0.679213 | 0.709854 | | |
| | −(0.525) | (0.654) | | |
| Rice price | 0.000311 | 0.000726 | | |
| | (0.214) | (0.527) | | |
| Northern dummy | −0.083865 | −0.110648** | | |
| | −(1.944) | −(4.113) | | |
| Northeastern dummy | 0.016770 | −0.002481 | | |
| | (0.390) | −(0.088) | | |
| Southern dummy | 0.168381** | 0.142552** | | |
| | (4.081) | (4.033) | | |
| Central dummy | 0.014056 | 0.004991 | | |
| | (0.450) | (0.197) | | |
| Adjusted $R$-squared | 0.7265 | 0.7550 | | |
| Number of observations | 290 | 290 | | |

*Notes:* Data are pooled for 1976, 1978, 1982, 1985, and 1989; *t*-statistics are in parentheses.

[a] (Instruments: nonagricultural GPP per capita, nonagricultural GPP per capita squared, nonagricultural household density, nonagricultural household density squared, distance * slope).

[b] Based on the 2SLS model; ** statistically significant at 1% level; *statistically significant at 5% level.

tion density is −0.82 for the North/Northeast section of the country and −0.46 for the South/Central region.

Our elasticity of forest-to-total area with respect to population density for the North/Northeast section of the country (−0.82) is still considerably lower (in absolute value) than Panayotou and Sungsuwan's (1994) figure for the Northeast alone, which they estimate using data from 1973–82. To compare our elasticity with that of Panayotou and Sungsuwan (1994), we estimated the cleared land equation for the Northeast section of the country alone, using data for the period 1976–89.[11] Our elasticity of forest area with respect to agricultural population density, −2.19, actually exceeds in absolute value Panayotou and Sungsuwan's (1994) estimate of −1.50. We note the reason for our large estimated elasticity for the Northeast is not due to any difference in the coefficient of agricultural household density between the North/Northeast and the Northeast alone (the coefficients are virtually identical). Instead, it is due to the low ratio of forest-to-total area in the Northeast that is used to compute the elasticity estimate. In any event, the impact of population on land clearing in the Northeast of the country does not appear to be typical of impacts in the rest of Thailand.

[11] Because we cannot obtain data on non-agricultural GPP for 1973, we cannot use data for the same period as Panayotou and Sungsuwan (1994).

TABLE 2

2SLS AND OLS RESULTS FOR NORTH AND NORTHEAST REGIONS COMBINED, 1976–1989

Dependent Variable: Proportion Cleared

| Independent Variables | 2SLS Results[a] | OLS Results | Elasticity of % of Land Cleared[b] | Elasticity of % of Land Under Forest Cover[b] |
|---|---|---|---|---|
| Constant | 0.446396* | 0.553427 | | |
| | (2.266) | (3.347) | | |
| Agricultural household density | 0.024462** | 0.011709** | 0.4082** | −0.8175** |
| | (2.914) | (3.311) | | |
| Road density | −1.438438 | 0.631042 | | |
| | −(1.231) | (1.733) | | |
| Percent slope >30 | −0.004066** | −0.004082** | −0.2176** | 0.4358** |
| | −(5.681) | −(9.159) | | |
| Percent acrisol | 0.001718 | 0.000450 | | |
| | (1.403) | (0.508) | | |
| Distance to Bangkok | −0.000250** | −0.000258** | −0.2013** | 0.4031** |
| | −(3.906) | −(4.598) | | |
| Log price | 3.549870 | 1.732827 | 0.2838 | −0.5684 |
| | (1.767) | (1.161) | | |
| Rice price | 0.001932 | 0.001377 | | |
| | (0.930) | (0.739) | | |
| Adjusted $R$-squared | 0.7793 | 0.8158 | | |
| Number of observations | 160 | 160 | | |

*Notes:* Data are pooled for 1976, 1978, 1982, 1985, and 1989; $t$-statistics are in parentheses.

[a] (Instruments: nonagricultural GPP per capita, nonagricultural GPP per capita squared, nonagricultural household density, nonagricultural household density squared, distance * slope).

[b] Based on the 2SLS model; **statistically significant at 1% level; *statistically significant at 5% level.

*2. The role of roads in explaining land clearing.* While population pressures played a more important role in land clearing in the North of Thailand than in the South, the opposite is true of the road network. The elasticity of proportion of land cleared with respect to road density is approximately 0.5 in the South. The elasticity of forest area with respect to road density is much higher in absolute value (−1.47) than the elasticity of forest area with respect to population density (−0.46).

In the North, by contrast, road density does not have a statistically significant impact on land clearing. This somewhat surprising result must, however, be qualified. Although road density is not statistically significant, timber prices are (at the 10% level), and have a sizeable impact on forest area. (The elasticity of forest area with respect to timber price is −0.57.) It is likely that timber prices may provide a good proxy for logging roads, whereas extensions of the road network, as measured by $R$, may not take place near forests.

*3. The role of other factors.* 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 4.3% 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 difference in percentage of slope greater than 30% has no statistically significant impact on the fraction of the province cleared. Topography has thus provided forests with more protection in the North than in the South.

Poor soil quality, on the other hand, has

TABLE 3

2SLS AND OLS RESULTS FOR SOUTH AND CENTRAL REGIONS COMBINED, 1976–1989

Dependent Variable: Proportion Cleared

| Independent Variables | 2SLS Results[a] | OLS Results | Elasticity of % of Land Cleared[b] | Elasticity of % of Land Under Forest Cover[b] |
|---|---|---|---|---|
| Constant | 0.440627** | 0.511303** | | |
| | (2.823) | (3.707) | | |
| Agricultural household density | 0.014500** | 0.006886** | 0.1543** | −0.4615** |
| | (2.643) | (2.556) | | |
| Road density | 2.737102** | 2.04608** | 0.49315** | −1.4749** |
| | (5.044) | (7.769) | | |
| Percent slope >30 | −0.000244 | −0.001601** | | 0.0462 |
| | −(0.312) | −(3.630) | | |
| Percent acrisol | −0.001362** | −0.000874* | −0.1309** | 0.3916** |
| | −(2.631) | −(2.080) | | |
| Distance to Bangkok | 0.00005** | 0.00007** | 0.0381** | −0.1140** |
| | (2.757) | (4.030) | | |
| Log price | −1.504850 | 0.097121 | | |
| | −(0.919) | (0.073) | | |
| Rice price | −0.000469 | 0.000004 | | |
| | −(0.245) | (0.002) | | |
| Adjusted $R$-squared | 0.5288 | 0.6526 | | |
| Number of observations | 130 | 130 | | |

*Notes:* Data are pooled for 1976, 1978, 1982, 1985, and 1989; $t$-statistics are in parentheses.

[a] (Instruments: nonagricultural GPP per capita, nonagricultural GPP per capita squared, nonagricultural household density, nonagricultural household density squared, distance * slope).

[b] Based on the 2SLS model; **statistically significant at 1% level; *statistically significant at 5% level.

reduced the rate of land clearing more in the South than in the North. Our 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.[12] 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 4% 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.

Ironically, the role of economic factors (transport costs and agricultural prices) in explaining land clearing is mixed. The price of rice is never statistically significant in explaining land clearing.[13] Regarding transport costs, in the North/Northeast, the fraction of land cleared is smaller the farther the province is from Bangkok. This may reflect the fact that net returns from export crops are smaller the farther a province is from Bangkok. On the other hand, in the South and Central Plain the fraction of the province cleared increases with Distance from Bang-

[12] Fluvisol, gleysols, and acrisols are the most common of the 26 FAO/UNESCO soil groupings 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.

[13] A referee suggested that the prices of maize and cassava might do a better job of explaining land clearing since these upland crops are more likely to replace the forest than rice. When we estimated Tables 1–5 with the prices of maize and cassava replacing the price of rice, we also found these prices to be statistically insignificant.

TABLE 4

2SLS AND OLS RESULTS FOR NORTHEAST REGION ONLY, 1976–1989

Dependent Variable: Proportion Cleared

| Independent Variables | 1976–89 2SLS Results[a] | 1976–89 OLS Results | Elasticity of % of Land Cleared[b] | Elasticity of % of Land Under Forest Cover |
|---|---|---|---|---|
| Constant | 0.575519** | 0.745659** | | |
| | (3.835) | (8.121) | | |
| Agricultural household density | 0.024521** | 0.009633** | 0.4170** | −2.1976** |
| | (3.302) | (5.130) | | |
| Road density | −0.855950 | 0.236053 | | |
| | −(1.200) | (1.369) | | |
| Percent slope >30 | −0.000713 | −0.002156** | | |
| | −(0.829) | −(6.075) | | |
| Percent acrisol | −0.001458 | −0.001944** | −0.1508* | 0.7951* |
| | −(1.685) | −(3.3311) | | |
| Distance to Bangkok | 0.00008 | −0.00009 | | |
| | (0.762) | −(1.758) | | |
| Log price | 1.129330 | 1.635629 | | |
| | (0.808) | (1.958)* | | |
| Rice price | 0.001732 | 0.001830 | | |
| | (1.225) | (1.814) | | |
| Adjusted $R$-squared | 0.7012 | 0.8303 | | |
| Number of observations | 80 | 80 | | |

*Notes:* Data are pooled for 1976, 1978, 1982, 1985, and 1989 or for 1973, 1976, 1978, and 1982; $t$-statistics are in parentheses.
[a] (Instruments: nonagricultural GPP per capita, nonagricultural GPP per capita squared, nonagricultural household density, nonagricultural household density squared, distance * slope).
[b] Based on the 2SLS model; **statistically significant at 1% level; *statistically significant at 5% level.

kok. This is very likely due to the fact that most provinces close to Bangkok were excluded from our 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 the sample. Had they been included, the coefficient of distance would likely be negative.

## IV. 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. Steep slopes have provided protection in the North of Thailand but not in the South, while the opposite is true of poor soil quality.

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 15%. By contrast, in the North and Northeast an increase in road density appears to have had no statistically significant impact on land clearing.

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 8.1% decrease in forest area. In the South, this same increase caused only a 4.6% reduction in forest area.

After examining the impacts of roads and population pressures on deforestation in Thailand, it is tempting to ask the question: Armed with this knowledge, how could the Thai government have slowed the pace of land clearing during the 1970s and 1980s? The real interest here centers on the North and Northeast of Thailand, where the loss in forest cover during the 1970s and 1980s was far greater than in the South and Central regions. What do our results suggest would

TABLE 5
AGRICULTURAL HOUSEHOLD AND ROAD DENSITY EQUATIONS: FIRST-STAGE (OLS) RESULTS POOLED MODEL (1976, 1978, 1982, 1985, 1989)

| Dependent Variable | Agricultural Household Density | Road Density |
|---|---|---|
| Constant | −0.655031 | 0.023407 |
| | −(0.212) | (0.733) |
| Nonagricultural household density | 1.035023** | 0.006787** |
| | (9.694) | (6.160) |
| Nonagricultural household density squared | −0.029451** | −0.000197** |
| | −(9.303) | −(6.042) |
| Nonagricultural GPP per capita | −0.045870** | 0.00002 |
| | −(3.594) | (0.195) |
| Nonagricultural GPP per capita squared | 0.000113** | 0.0000006 |
| | (2.579) | (1.478) |
| Distance to Bangkok * slope | −0.00003 | −0.0000002 |
| | −(1.381) | −(0.484) |
| Percent slope >30 | −0.064207 | −0.000391** |
| | −(4.469)** | −(2.640) |
| Percent acrisol | 0.003824 | 0.000297** |
| | (0.323) | (2.428) |
| Distance to Bangkok | 0.001280 | 0.000021273 |
| | (0.793) | (1.277) |
| Log price | 112.519219** | 0.924520** |
| | (3.708) | (2.953) |
| Rice price | 0.031969 | 0.000425 |
| | (0.866) | (1.116) |
| Northern dummy | 2.825984** | −0.016396* |
| | (3.767) | −(2.118) |
| Northeastern dummy | 4.569336** | 0.000012160 |
| | (5.310) | (0.001) |
| Southern dummy | 0.658942 | −0.017072 |
| | (0.686) | −(1.723) |
| Central dummy | −0.221279** | −0.012241 |
| | −(3.708) | −(1.598) |
| Number of observations | 290 | 290 |
| Adjusted $R$-squared | 0.7019 | 0.4866 |

*Note:* $t$-statistics are in parentheses.
**Statistically significant at 1% level; *statistically significant at 5% level.

have retarded the pace of land clearing? As Tongpan et al. (1990) suggest, expanding income-earning opportunities outside of the agricultural sector may help, but according to the first stage of our regressions (see Table 5), the impact is not large. (The elasticity of agricultural households with respect to non-agricultural GPP is only −0.2.) Making logging less profitable would have had an impact (the elasticity of agricultural households with respect to log prices is 0.62), and this is ultimately what the government attempted to do by banning logging in 1989. While our evidence on the role of road building in promoting deforestation in North Thailand is mixed, we believe that a more micro analysis of the impact of roads on land use would yield useful results, and are currently pursuing such an analysis.

## APPENDIX
### DESCRIPTION OF THE DATA

#### *A. Cleared Land*

The dependent variable in the model is fraction of the province cleared, but these data are not published. 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,[14] 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 of 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 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.

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 is 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.[15] This map identifies 106 categories of soil type, 15 of which were found in Thailand. They were collapsed into three broad categories: fluvisol, gleysol, and acrisol. 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, 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

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[14] Ground truthing implies verification of the satellite pictures of forests using aerial surveys (usually done using helicopters), as well as direct observation.

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

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, are 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 years 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 *National Statistical Yearbooks*. They contain annual data for the entire Kingdom for the years 1971–1990.

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