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HEADLINE: Deforestation and Ownership: Evidence from Historical Accounts and Contemporary Data; Statistical Data Included

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**AUTHOR-ABSTRACT:**

Historical accounts of forest cover changes over the last three millennia are compared to contemporaneous human history, to shed light on factors contributing to large scale changes in forest stocks. Insecure ownership, for example, during wartime and periods of unrest, tends to accompany deforestation, as does population growth, and as does declining agricultural yields. A simple model of forest stocks and agricultural yields that captures these relationships is formulated to guide empirical analysis. Estimates based on cross-country data support the proposition that agricultural yields tend to be low and deforestation rates rapid where ownership is insecure.

**BODY:**

**I. INTRODUCTION**

The factors that cause forests to advance or decline are assessed using a source of information that economists have largely overlooked, historical accounts of forest cover changes in specific regions of the world and the human history that accompanied the changes.(1) This source is potentially attractive because it covers long time spans. Deforestation and afforestation are often gradual processes and may be difficult to observe with data that cover only a few years. A limitation, of course, is that the historical record often is impressionistic, and only rarely quantitative. The historical literature surveyed makes no mention of the writings of economists on deforestation. This independence is potentially advantageous because it forces a degree of objectivity that might otherwise be difficult to attain. The selection of episodes described in this literature may have been influenced by the expectations and preconceptions of historians, but they apparently were not influenced by the theorizing of economists.

There is no guarantee, however, that the specific historical accounts selected for description in the present paper are immune from the same biases. Anyone who has engaged in an exercise of this sort, compiling published historical episodes and anecdotes to assess causes for a specific phenomenon, must wonder whether they are being objective in representing what the historical evidence shows. One way to guard against drawing false inferences on this account is to test the conclusions that emerge from the historical accounts empirically. This approach is taken here, using cross-country observations on forest cover for recent periods, together with other relevant data.

Forest cover is declining globally, at a rate of about 1% per year in the 1980s.(2) Understanding the forces that are shaping this trend is of intrinsic economic interest because it represents a major reallocation of the world's land resources. Loss of forests specifically, whether through conversion to cropland, pasture, or wasteland, is of interest to policymakers due to the important unpriced services forests provide.

Deforestation is an important cause of increases in atmospheric carbon, species extinction due to habitat destruction, and displacement of indigenous forest dwellers. A quick examination of cross-country data reveals that deforestation rates vary widely among countries.(3) Theoretical and empirical studies have examined the role of several

factors, including population growth, income, government policies, and insecure ownership. The primary focus here is on the last of these, although the evidence presented also sheds light on the role of other factors.

Economists often claim that insecure ownership hastens the clearing of forests. This prediction stems from a partial equilibrium argument that regards forest biomass as a form of capital, and characterizes ownership risk as equivalent to an increase in the interest rate applied to its future returns. Theory predicts that insecure ownership will induce short harvest rotations on forests cut for timber or biomass for shifting cultivation. Short rotations, in turn, can cause forest land to degenerate into wasteland. Theory also predicts that insecure ownership will deter replanting after forests are cleared. More specifically, insecure ownership weakens incentives to encourage regrowth in cutover forests or to plant and protect village wood lots for timber and fuel. Such investments would tend to reduce pressure on natural forests.

Ownership risk in an economy is likely to be a general condition, however, that discourages incentives to accumulate all forms of capital, natural and produced. If forest biomass and produced capital are complements, the direct effect described in the preceding paragraph could be offset. Two examples illustrate this: harvesting forest nutrients for slash and burn agriculture is facilitated by roads, and harvests of commercial timber require the availability of saw mills. If ownership risk prevents the accumulation of such complementary produced capital, deforestation might actually be lower when ownership is insecure.<sup>(4)</sup> Alternatively, if forests and produced capital are substitutes, the direct effect of insecure ownership on deforestation would be augmented. For example, investments in irrigation, terracing, soil enrichment, and farm machinery tend to increase the yield obtained from each acre planted.<sup>(5)</sup> Ownership risk deters such investments and reduces agricultural yields, causing more forest land to be cleared if food demands are inelastic. Certain historical episodes seem to illustrate this possibility.

The economic literature on deforestation is fairly extensive and the topic of tenure security is a growing theme. Mendelsohn (1994) develops partial equilibrium models suggesting that insecure ownership will lead to land use decisions that reduce forest cover. Empirical studies based on cross-country data include Cropper and Griffiths (1994), who focus on deforestation and economic development, and Deacon (1994) who examines evidence on deforestation and the rule of law. Using regional data, Southgate, Sierra, and Brown's (1991) study of Ecuador demonstrates that deforestation is lower where land claims are more secure. Alston, Libecap, and Schneider (1996) show that adjudicated land claims enhance incentives for agricultural investments in Brazil. Godoy et al. (1996) infer a tenure security effect data on income and forest clearance in Bolivia. Lopez (1996) assesses the efficacy of community controls in forest management in Ghana. Godoy et al. (1996, p. 981), summarizing micro-level economic and ethnographic studies, conclude that: secure ownership, capital intensive, high-yield farming, and relatively light deforestation pressure tend occur together. Additional empirical literature is discussed in later sections.<sup>(6)</sup>

## II. HISTORICAL ACCOUNTS

The following survey is necessarily eclectic as the available literature does not provide a unified account of forest cover changes and related events in human history for all regions and periods. Histories that simply describe forest cover changes without attempting to relate them to social or economic conditions are omitted. Certain works stand out among those included either because they are unusually detailed or because they focus tightly on the social forces that affect forests. The most prominent of these is Thirgood (1981) who traces the history of forests in the Mediterranean region over the last three millennia by piecing together information from historical records, literary sources, works of art, and scientific study. Bechmann (1990) presents a fairly complete history of forests in France from A.D. 1000 on, and emphasizes how forest cover changed between times of peace and war. Peluso (1992) describes how the forests of Java were used between 1942, when the island was invaded by the Japanese army, and the mid 1970s when a long period of internal strife ended. Spotty information for other periods and regions, including some evidence from the Inca and Maya civilizations, is also woven into the presentation.

### Evidence of Forest Conservation under Stable Civilizations

Thirgood's (1981, 150-51) history of forests in the Mediterranean basin emphasizes the role of political stability and well established rule of law for the practice of forest conservation. The Roman civilization provides several examples that illustrate this point. Forest legislation under the Roman Republic dates to the fifth century B.C., when forests were sacred and were overseen by forest guardians associated with the priesthood (Anon. 1967). By 400 B.C., the Republic claimed ownership of forests in land it controlled and relied on a cadre of forest custodians to guard and patrol it. This ancient "forest service" eventually became responsible for tending and managing the forests, for controlling harvests, and for protecting of watersheds. Thirgood (1981, 44) describes forest guards, who "enforced respect for contracts, controlled exploitation and grazing, and performed many of the functions of a modern forest service." He also notes that "Woodlands were enclosed for state and private hunting preserves [land] land leases and

published decrees were issued containing restrictions on timber cutting and stipulations for replanting." (7) Bechmann (1990) reports on forest management practices by the Roman Empire in Gaul, and notes that three types of forest area were designated, with specific uses and harvest rotation ages for each.

Purposeful investments in forest growth are also attributed to classical civilizations. Mirov (1967, 4, 5, 245, 247) reports that significant tree planting was undertaken by Etruscans, Romans, and others, and that pines were introduced into many regions of the Mediterranean basin where they had not grown naturally. Romans regularly maintained coppice woods with annual cuts - Pliny, in his *Historia Naturalis*, mentions specific rotation periods for harvests of chestnut and oak (Thirgood 1981, 45).

State sanctioned forest conservation was practiced in ancient Greece, with laws on forest use administered by local magistrates. Plato's laws included special provisions for "holy" areas in Greek forests (Thirgood 1981, 43) with fines for illegal use and prohibitions against setting fires and removing wood and leaf fodder. (8) This extended to early Ptolemaic Egypt (circa 330 B.C.) where the felling of trees was under state control, with penalties for unauthorized use. Thirgood (1981, 92) refers to "a country-wide programme of tree planting on wasteland, private property and royal estates, and along the banks of rivers and canals." Trees were raised on state plantations, where laws regulated felling, lopping, and removal of fallen trees, and provided for exclusion of sheep and goats from young groves.

Bechmann (1990, 207-8) presents no specific details, but does comment on the conditions necessary for provision of large dimension timber from the forests of France during the Middle Ages. He points out (208) that "Only human beings with a sense of history, groups of people who could count on a certain stability in time . . . could take such measures: religious communities, dynasties of kings or high lords, noble families."

In the New World, Moore's (1957) remarkable treatise on Inca law and government provides evidence of a sophisticated and stable system of land tenure in that civilization. Her descriptions are drawn from accounts of priests, soldiers, and Spanish government officials as well as extensive surveys of indigenous populations by the sixteenth century Conquistadors. Of specific relevance here, Moore (1957, 65) points out that ownership of all woodlands and hunting grounds was claimed by the ruling caste. These lands could be used by local community residents to obtain wood for fuel, building materials, and hunting, but only if permission was granted by the regional governor. Cutting trees without permission was punishable by death. (9)

#### Evidence of Forest Decline in Times of War, Revolution, and Enemy Occupation

Security regarding claims to assets and their returns arguably is at a minimum during times of war, invasion, enemy occupation, and anarchy. A description of forest use in such volatile times provides instructive counterpoint to the forest practices employed during the stable circumstances just described. Social unrest might affect forests in two opposing ways. The insecurity that accompanies war reduces conservation motives to minimal levels, and this tends to reduce forest cover. War often causes the annihilation or enslaving of populations, however, and the consequent reduction in demand for timber and forest land might allow forests to expand. Both views are expressed in the literature.

Thirgood (1981, 58) concludes that the net effect of war on the Mediterranean forests has clearly been destructive. Some of this destruction is direct - the use of wood in war implements, the use of fire in battles, and so forth. He claims (58) that the more important force is due to the undermining of security, however, arguing that

wars and invasions have had a profound effect in upsetting established use patterns. In the Mediterranean environment there is a clear relationship between the security that accompanies stable government and good husbandry of the land. Disruption of settled government has almost inevitably led to an increase in pastoralism. This has been so from the breakdown of the Roman Empire, when the nomads were no longer kept beyond the frontiers, through the Moslem invasions of the early Middle Ages, and the upheavals of the Crusades, down to the disruptions of the Second World War and its aftermath.

Thirgood also recounts specific examples of war's effects in southern Italy, Greece, and elsewhere. In his estimation the Greek forests suffered extensive devastation in the confusion that followed the Greek War of Independence in 1821. He notes (58): "At this time, and during subsequent periods of national emergency, political instability resulted in the destruction and degradation of many forest areas that had previously been protected by their inaccessibility."

Fernow (1913, 10) speaks of the "widespread devastation of large forest areas" during the Jewish wars chronicled by the historian Josephus. He also notes that the Persian wars in Greece that preceded the ascendancy of Alexander the Great caused widespread forest destruction. In Lithuania, it is reported that in an attempt to hinder Crusader armies, the

population felled vast areas of forest and made defensive lines with the fallen timber. According to the Republic of Lithuania Ministry of Forestry (1994, 17) forest tracts in this section of the country remain sparse to the present day.

The susceptibility of forests to destruction by fire makes them uniquely vulnerable during time of war or political unrest. Firing the forests can both be a war-making tactic and a way to deny resources to one's enemy. Thirgood (1981, 67) describes its use as a weapon in the Persian invasions of Greece, in the Peloponnesian War between Athens and Sparta, during the Arab Invasions of North Africa, and in the Mamelukes defense of the Levant against the Crusaders. Bechmann (1990, 267) reports that during the late thirteenth century kings Edward I and Henry II set fire to forests in Wales and Ireland in order to dislodge indigenous enemies. As part of the re-conquest of Spain from the Moors during the Middle Ages, many forests were burned to deny shelter and strong points to defenders. In fourteenth century Russia, Tamerlane burned forests to dislodge the Slavs.(10)

Absent outright warfare, forest destruction can follow from revolution and the disintegration of established governments. Fernow (1913, 10) notes that in Great Britain during the revolution of Cromwell, beginning in 1642 and during Cromwell's reign, "a licentious devastation of the confiscated or mortgaged noblemen's woods took place." He also notes (373-74) that large areas of woodland along the Scottish borderland, originally maintained by residents for domestic use, was laid waste in Cromwell's time.

Lowenthal (1956, 275 ff.) reports on the record from France during and after the Revolution. He cites the turmoil and excesses of the Revolution, "the wiping out of feudal forest privileges and widespread pillaging which followed," together with the abolition of ecclesiastical claims to vast forest tracts, as sources of forest reduction.(11) Fernow (1913, 219) elaborates on this theme, explaining that the French revolutionary law of 1791 abolished existing jurisdictions and legal restraints on land use but put nothing in their place. The result was "widespread destruction and devastation of forest property against which legislative attempts of the republican government were entirely powerless."

Particularly rapid devastation of European forests accompanied World War II. Teclaff (1956, 307-8) describes the history of East-Central European forests during the twentieth century and notes that the most rapid losses occurred during this conflict. The rate of forest cutting in Poland during the five years of German occupation was nearly three times as rapid as in prewar days. A United Nations forestry report on the entire continent reports that vast areas of European forest suffered heavy damage during the war, "from excessive and destructive cutting, actual war devastation, and wholly inadequate reforestation" Teclaff (1956, 308). Lowenthal (1956, 275-77) notes that "over cutting" occurred in France during and immediately following World War II. He also reports data showing that forest cover in France advanced steadily from 1863 to 1953, except during the World War II, when it declined. Forest destruction during the Japanese occupation of Indonesia and the 30 years of revolution that followed is examined next.

#### The Fate of Java's Forests During Enemy Occupation and Revolution

In 1942 the Japanese Army invaded and occupied Java, and effectively brought nearly 150 years of Dutch colonial rule to an end.(12) When the Japanese were driven out in 1945, the Republic of Indonesia declared itself an independent state. Shortly thereafter the Dutch, aided by British troops, fought unsuccessfully to reestablish their authority in Indonesia. When the Dutch withdrew in 1949 they left a new nation steeped in civil strife. The Islamic fundamentalist Darul Islam, the Indonesian Communists, and the Army of the Republic of Indonesia all struggled for control. Although the Army eventually dominated, sporadic violence for control of the countryside continued into the 1970s (Peluso (1992, 91, 93, 97-98, 102-6). Notions of forest management, forest access rights, and forest control were confused during this entire period, due to a breakdown of the state's capacity to control the resources it claimed. The result was widespread forest destruction.

Directly and indirectly, the Japanese occupation resulted in damage to Java's forests that is still visible. Older trees were destroyed and few trees planted during the occupation and subsequent revolution. In order to produce timber rapidly to support their war effort, the Japanese created forest villages by settling colonies of woodcutters in previously unexploited areas. The areas cut were then converted to agriculture. Forest villagers who lived through this chaotic period refer to the cutting as "rampant and ubiquitous" (Peluso, 1992, 96). When Dutch rulers fled the Japanese invasion, local villagers took this as a "signal that old forms of control were being released, and in their absence villagers rushed to openly claim wood or territory from a long forbidden source" (Peluso, 1992, 121).

During the revolution that followed the Japanese exodus, the Indonesian Forest Service was largely prevented by the conflict from carrying out traditional management practices. Control of access to forests was relatively ineffective.(13) During the first year of the revolution, 1946, an estimated 220,000 hectares of state forest, roughly 7% of the total stock, were destroyed or damaged. About half of this acreage was destroyed by fires, roughly 10 times as

much as during a comparable period of Dutch colonial rule, and the remainder was occupied by forest villagers or cleared by peasants and armies for fuel. In some instances "battalions of armed villagers" entered teak forests and removed all trees. By the end of the revolution in 1949, at least 14% of Java's state forest lands were occupied by peasants or deforested by civilian and military wood thieves.

Peluso reports that, with the end of the revolution and Dutch withdrawal in 1949, a long period of civil strife ensued. The military, fighting against the Darul Islam, purposely burned large tracts of forest to force the insurgents out and to prevent their return. Wasteful cutting and wood removal by villagers and military officers was also common since "Given the turbulent atmosphere of the times, many foresters were afraid to take action" (Peluso 1992, 110). Foresters were occasionally able to forge a bond with local military and police to guard the forest, "But whenever [such cooperation] ended, as it would always have to, they couldn't keep people from taking trees" (Peluso 1992, 110).

#### The Role of Stability in Agricultural Investment and Consequent Effects on Forests

Several writers offer evidence that ownership security affects forests indirectly, through agricultural investments. Secure ownership promotes investments in irrigation, terracing, soil enrichment, and farm capital, all of which tend to increase crop yields per acre. For an economy that farms primarily to meet inelastic subsistence food requirements, the net effect is to reduce the acreage of forest land cleared for agriculture.(14)

There is widespread evidence that stable civilizations have created conditions amenable to sophisticated agricultural investments. Reifenberg (1955, 83) reports that Hammurabi, the Amorite king who ruled during the rise of the Babylonian Empire around 1700 B.C., adopted a land code that required owners to keep irrigation canals, dikes, and river embankments in good repair, while the state built and maintained major water works. The same author describes sophisticated agriculture in Palestine during the eighth century B.C., and emphasizes the need for a strong administration to protect flourishing agricultural communities from nomadic raids (Reifenberg 1955, 87).

Advanced agricultural methods were used by Greek and Roman civilizations during the first millennium B.C., including mechanical and chemical improvement of the soil, plant breeding, introduction of exotic species, and the practice of soil conservation (Thirgood (1981, 28-30). Roman agricultural practice in Palestine included terracing, centralized seed production, routine use of fertilizers, planting of orchards, and maintenance of windbreaks, irrigation works, and aqueducts. Thirgood (1981, 109-10) concludes that "these conditions, with all they implied for intensive care and investment in terrace maintenance and intensive agriculture, could only persist so long as there was a stable government." In a different venue, Moore (1957, 91) points out that the Inca empire levied taxes to provide irrigation works and other forms of public capital.

In the southern and eastern Mediterranean basin, capital intensive agriculture was practiced during the Pax Romana and the relatively stable era of Byzantine rule that followed. Murphey (1951, 120, 122, 125) catalogs archaeological evidence of Roman investments in water delivery systems and other agricultural capital during their rule of North Africa. Significantly, he notes that these improvements lasted only as long as North Africa was ruled by stable laws and government.

This peaceful period was followed by social turmoil. Several writers cite this breakdown of law and order as a cause of the decline of agricultural investments in the Mediterranean basin, particularly in the Middle East. Thirgood (1981, 22) ascribes the contraction of settled agriculture in the Eastern Mediterranean largely to political instability and economic decline in the disintegrating Roman Empire and to the invasion of nomadic tribes. He notes that the landscape was transformed from agriculture to pastoralism, and that failure to maintain terracing on hills hastened soil erosion. Reifenberg (1955, 80) and Murphey (1951, 124) both cite the decline of stability, and particularly invasions by nomads, as central reasons for the decline of agricultural investments in the Levant. Although none of these observers presents direct evidence on crop yields, it seems inescapable that yields fell.

Stable government may also promote agricultural investments by enabling settled agriculturalists to organize and collectively defend their property.(15) Such defenses broke down in the Middle East in the seventh and eighth centuries, and agricultural investment declined and deforestation ensued when nomadic cultures wrested control of land. Thirgood (1981, 70) observes that: "Throughout the Mediterranean, vast areas legitimately belonging to crop husbandry have been taken over by pastoralists in the absence of strong central government." Reifenberg (1955, 80) commenting on the deforestation, soil erosion, and sanding-up of fertile land in the Middle East, particularly in Mameluke and Turkish times, draws a connection between such deterioration and the inability of settled agriculturalists to repel nomadic incursions. More generally, he observes: "It can be shown that it was in periods of firm rule only that agriculture

flourished in the country. . . . We see again and again that the desert spreads over all forms of civilization whenever a deterioration of political conditions ensues."

Several authors cite the nomadic culture, lacking permanent ties to specific parcels of land, as a force tending to prevent the regeneration of forests on untilled land and subsequent recovery of the land's natural productivity.(16) In many cases, of course, the marginalized status of these populations is due to their displacement by settled states. In any case, Thirgood (1981, 69-71) considers grazing by nomadic cultures to be the most obvious and probably the most significant process in the loss of Mediterranean forests, mainly due to close cropping of new tree buds by goats and sheep. He is careful to point out that while Roman agriculturalists grazed animals, the form this grazing took was different and far less destructive than that practiced by the nomads who followed them. Intentional deforestation to increase grazing land, a common practice in less settled cultures, is never mentioned among Roman treatises on agriculture. He also notes that the Romans placed much importance on defenses to keep the nomad's flocks and camels beyond the bounds of cultivated lands. In his study of Jordan, Waterer (1949) stresses that it is not grazing per se that is damaging, but rather grazing by migratory flocks that have no connection to specific parcels of land.(17) Overall, because the agriculture practiced by pastoral nomads uses more land per unit food output, for example, calories, than settled agriculture, these observations are consistent with the hypothesis advanced earlier - that deforestation is promoted by reduced agricultural yields.

#### Deforestation, Disinvestment, and Social Collapse in the Maya Civilization

Several studies point to a sequence of events in ancient Mesoamerica that resembles episodes from the Mediterranean Basin. Available evidence indicates that the Maya population began to spread over the Mesoamerican lowlands around 2000 B.C. Structured political institutions and significant capital accumulation began to emerge in the late pre-Classic era, roughly 300 B.C. to A.D. 1 (Blanton et al., 1981, 185; Cliff and Crane 1989.) Significant agricultural investments such as canals, reservoirs, terraces, and raised fields, first appear in this period and the pollen record indicates a trend away from shifting cultivation toward settled farming (Cliff and Crane 1989; Matheny 1982, 168-69.) During the Classic period, roughly A.D. 250-900, archaeological evidence shows that Maya populations were ruled by an elaborate system of state and regional government, capable of erecting collective defenses (Blanton et al. 1981, 201-2). Formation of permanent capital was extensive, individuals or families accumulated wealth, and agriculture became more intensive (Blanton et al. 1981, 191-204; Abrams et al. 1996, 58-64). Population levels increased beyond anything achieved since.

Sometime between A.D. 800 and 900, the classic Mayan way of life fell apart, particularly in the southern region. New construction virtually ceased and population centers were largely abandoned. The archaeological record indicates a rather abrupt, widespread collapse of the system of government. Several observers cite warfare, internal rebellion, and political disintegration as likely factors. Others postulate that the end may have been precipitated by disease or natural disaster (Blanton et al. 1981, 208; Abrams et al. 1996, 56.) Whatever the cause, the ability to govern was lost. Abrams et al. (1996, 69 ff.) examine the pollen record and conclude that extensive deforestation occurred around the time of social collapse.(18)

This overall pattern of events now sounds familiar. Evidence from other parts of the world suggests that rapid deforestation in Mesoamerica may have resulted from failure of a system of forest and land use controls, for example, a sharp decline in fallow periods, failure to maintain terraces and raised fields, and premature harvesting of growing trees, and that this was just one of many unfortunate consequences of social disintegration. Abrams et al. (1996, 58, 59, 71-72) would disagree with this line of causation.(19) Unfortunately, our knowledge of Mayan history is not sufficiently detailed to determine causation.

#### Other Factors: Stability Leading to Population Pressure, and Religious Influences

Some have argued that war and instability can promote the spread of forests, by reducing population and thereby lowering pressure to harvest timber and convert forest land to agriculture. Thirgood (1981, 30) observes that the last 200 years before the Christian era was a period of civil wars, social revolution, and extensive slave hunting in the Mediterranean basin. One consequence of this turmoil was, he claims, a decline in population and reversion of much cultivated land to bush fallow and forest. Similarly, he concludes that population growth throughout the Mediterranean region in modern times has led to accelerated land clearance (Thirgood 1981, 34). Elsewhere, he connects population growth to social stability by noting that "disruption of sound administration and security has repeatedly been reflected in decreases in population . . . in part [due to] diminution of the food producing base" (Thirgood, 1981, 63).

Bechmann (1990) believes that this occurred repeatedly in France. He reports that populations declined and forests advanced toward the end of the period of Roman rule and the great invasions of the fifth century. Following that period, "from Clovis to Charlemagne, a certain security and stability returned, the population increased, and [forest] clearings started once again" (Bechmann, 1990, 294). A subsequent episode started in tenth century when the Hungarians were expelled from the east and Saracens from the south, and the Normans settled in the north. This ushered in a period of relative peace between the end of the tenth and the middle of the thirteenth centuries which, according to Bechmann (1990, 48) resulted in population increases that rendered the existing cultivated land area insufficient. He claims (50) that this led to an expansion of agriculture at the expense of wooded areas: "Everywhere, the forest receded before the logger's axe and the settler's plow." This trend was subsequently reversed when populations were decimated by disease and war (294):

During the 14th century the Black Death and the Hundred Years War. . . . led to a drastic reduction in the population and, consequently, to a strong return of the forest. When during the following centuries a certain stability returned, the population started once again to grow and there were new cuts in the forests.

Overall, he seems to regard population fluctuations as the main agent of change in forest cover, at least in France.(20)

Religion is sometimes cited as a factor in the ebb and flow of forests. Religious practices can influence rules of land ownership in ways that affect investment and conservation incentives, regardless of the degree of stability and security. Hughes (1980, 47-49) describes the preservation of sacred groves of trees by the Greeks and Romans: "Cities passed laws forbidding the cutting of trees, removal of wood or leaves, pasturing of cattle, sheep or pigs, or planting of grain in sacred groves under penalty of stiff fines." The practical result was the survival of mature forest stands after adjacent areas had been deforested. Some writers regard the rise of early Christianity as a source of destruction of such forests. Fernow (1913) reports that sacred groves in ancient Greece were purposely destroyed by early Christians who regarded them as icons of a pagan religion. Bechmann (1990, 280) reports similar events in France during the early Middle Ages, where Christian theologians effectively declared war on forests as a way to suppress pagan cults centered around tree worship. According to Reifenberg (1955, 104), Moslem doctrine regards all uncultivated lands as commons, with rights of pasturage accorded to all herd-owners, and the same rule applies to cultivated land after harvest. He describes the resulting effect on natural vegetation as "devastating" and notes that the same doctrine allows most forests to be exploited without any restraint.

### Summary

Several broad generalizations emerge from these accounts. Investments in forest conservation and husbandry tended to occur under stable societies where the rule of law was well established. Incentives for such conservation actions fall to a minimum during times of war and revolution and following the breakdown of established systems of ownership, and forests tended to decline under such circumstances. Agricultural investments and measures to conserve the land's natural productivity are most prevalent in stable societies, and these investments deteriorate dramatically when the ability to protect them is lost. Reductions in agricultural investments tend to increase deforestation pressure by increasing the land area needed to support a given population.(21) Stability can promote population growth, however, which may increase demands for wood and crop land, causing forests to shrink. Also, religious beliefs can shape the use of forests in additional ways, whatever the ownership regime. The remaining sections present data and a model that allow some of these hypotheses to be addressed empirically.

### III. A MODEL OF DEFORESTATION AND AGRICULTURAL INVESTMENT

The following model is structured so that certain generalizations from the historical survey emerge as formal hypotheses. For reasons of tractability the model is partial equilibrium, and this should be borne in mind when interpreting results. In particular, the supply of labor and capital to agriculture and forestry are regarded as perfectly elastic. This may be a poor approximation in economies where agriculture and forestry are large economic sectors.

To begin, assume agricultural production ( $Y$ ) is a strictly increasing function of labor ( $L$ ), land ( $A$ ), and capital ( $K$ ) used in agriculture.(22) The form of the production function is assumed to exhibit weak separability of the following form:

$$Y = Y(f(L, A), K). [1]$$

Weak separability implies that the marginal rate of substitution between labor and land depends only on  $L$  and  $A$ , a property shared by the CES and its specialized variants. The reason for adopting this assumption will be apparent

momentarily. The demand for agricultural products is assumed perfectly inelastic with respect to price and increasing in population,  $N$ . This leads to a model that highlights interactions between forest cover, population, and agricultural productivity. It seems not unreasonable in economies where agriculture is primarily for subsistence.(23)

The production function [1] can be inverted to obtain  $h(Y, K) = f(L, A)$ , where  $h(\cdot)$  is increasing in  $Y$  and decreasing in  $K$ . One can now write a Hicksian demand for agricultural land, with  $Y$  and  $K$  considered fixed, as follows:

$$A = [A.sub.K]([R.sub.A]/w, h(Y, K)), [2]$$

where  $w$  is the wage and  $[R.sub.A]$  is the rent to agricultural land.  $[A.sub.K](\cdot)$  is decreasing in  $[R.sub.A]/w$ , increasing in  $Y$ , and decreasing in  $K$ . The separability assumption implies that the demand for agricultural land is decreasing in agricultural capital, which agrees with historical accounts.(24) Inverting [2] yields an expression for  $[R.sub.A]$ :

$$[R.sub.A] = [R.sub.A](A, w, K, Y), [3]$$

which is decreasing in  $A$  and  $K$  and increasing in  $w$  and  $Y$ .(25)

The rent on land devoted to growing forests for regular harvesting, for example, for commercial timber, fuelwood, or shifting cultivation, is specified by modeling all such land uses as forest rotation problems. Wood harvested for fuel may be grown in village coppice stands or harvested from community woodlands, and biomass cut and burned for shifting cultivation is harvested periodically to release nutrients into the soil. The value of an acre of land harvested periodically for biomass is given by

[Mathematical Expression Omitted] [4]

$P$  is the unit value of forest biomass,  $t$  is the age of a growing stand,  $B(t)$  is the biomass per acre, and  $C$  is the replanting cost per acre.  $[\Delta]$  stands for the discount rate associated with postponing receipts into the future. In situations where ownership is secure,  $[\Delta]$  equals the real rate of interest. If ownership is insecure, postponing an asset's return reduces the probability that the current owner will receive it. Assuming loss of ownership to be an all-or-nothing event, the effect of ownership risk on the expected present value of future returns is equivalent to an increase in  $[\Delta]$  (Bohn and Deacon 1997).

Given [4], the rental price of forest land is

$$[R.sub.F] = [\Delta] \cdot V([\Delta] P, C) \text{ [equivalent to]} [R.sub.F]([\Delta], P, C). [5]$$

$[R.sub.F]$  is decreasing in  $[\Delta]$  and  $C$  and increasing in  $P$ .  $P$  represents factors that determine the unit value of biomass. For commercial harvests the price of timber,  $[P.sub.F]$ , is the appropriate value. For fuelwood and agricultural nutrients, the marginal value of biomass will depend on local supply and demand factors. Demands for fuelwood and agricultural nutrients should depend positively on population,  $N$ . Supplies should be related to the share of land covered by forests,  $F$ , as this measures the relative abundance of forest biomass. Replanting cost,  $C$ , is likely to be dominated by labor, which suggests using  $w$  as a proxy. Making these substitutions, [5] can be written

$$[R.sub.F] = [R.sub.F]([\Delta], [P.sub.F], N, F, w). [6]$$

$[R.sub.F]$  is decreasing in  $[\Delta]$ ,  $F$ , and  $w$ , and increasing in  $[P.sub.F]$  and  $N$ .

Normalizing total land area to unity, we have  $A = 1 - F$ , which can be used to eliminate  $A$  from [3]. The allocation of land is in equilibrium when  $[R.sub.A](\cdot) - [R.sub.F](\cdot) = 0$ , or

[Mathematical Expression Omitted]. [7]

$Y$  (food output) has been replaced by  $N$  in  $[R.sub.A]$  because food demand was earlier assumed to be price inelastic and increasing in population. The signs below variables denote signs of partial derivatives. Inverting  $H(\cdot)$  gives an expression for equilibrium forest cover:

[Mathematical Expression Omitted] [8]

Forest cover is decreasing in  $[\Delta]$ , in keeping with the ownership security argument, and increasing in agricultural capital, as suggested by certain historical accounts. Increasing population will raise the demand for both agricultural land and land that can grow biomass, so the net effect on  $F$  is ambiguous.



Adding a time subscript,  $t$ , and assuming [8] to be linear, the empirical model is

[Mathematical Expression Omitted].

where  $[\epsilon]_{sub,t}$ , is a disturbance term and  $[Z]_{sub,t}$  is the vector of independent variables. Because forest cover is unlikely to move instantly from one long run equilibrium to another, a partial adjustment process is assumed. This implies the following empirical specification:

$$[F]_{sub,t} - [F]_{sub,t-1} = [Z]_{sub,t}[\Theta] - [\Lambda][F]_{sub,t-1} + [\mu]_{sub,t}, [9]$$

where  $[\Lambda]$  captures the speed of adjustment,  $[\Theta]$  [equivalent to]  $[\Lambda][\beta]$ , and  $[\mu]$  [equivalent to]  $[\Lambda][\epsilon]$ . The dependent variable,  $[F]_{sub,t} - [F]_{sub,t-1}$ , is "minus the deforestation rate."

A simple model of agricultural capital is based on the constant output demand for  $K$ :

$$K = K([\Delta]/w, [R]_{sub,A}/w, N), [10]$$

where  $Y$  has been replaced by  $N$ .  $K(\cdot)$  is decreasing in  $[\Delta]$ , increasing in  $N$ , and ambiguously related to  $w$  and  $[R]_{sub,A}$ . From [3] and [8] the factors that determine  $[R]_{sub,A}$  are  $w$ ,  $K$ ,  $N$ ,  $[\Delta]$ , and  $[P]_{sub,F}$ . Substituting, the equilibrium level of  $K$  can be written:

$$K = K([\Delta], w, N, [P]_{sub,F}). [11]$$

The effect of  $[\Delta]$  on  $K$  is theoretically ambiguous. In [10], the partial effect of an increase in  $[\Delta]$  is to reduce  $K$ . Increasing  $[\Delta]$  will also change  $[R]_{sub,A}$ , however, and the direction of change is ambiguous. Increasing  $[\Delta]$  lowers the demand for forest land. It raises the demand for agricultural land, however, if  $K$  and  $A$  are substitutes. The equilibrium land rent could either rise or fall, so the net effect of  $[\Delta]$  on agricultural capital is ambiguous.

Agricultural capital consists of heterogeneous inputs such as tractors, harvesters, irrigation equipment, and topsoil, plus improvements such as terracing, drainage ditches, and flood protection works. Data on these items are not widely available, and cross country quality differences may plague the series that are reported. For this reason, crop yield per acre is used as a proxy for agricultural capital, both as the dependent variable in [11] and as an independent variable in [9]. An added benefit of this substitution is a better connection with the literature on crop yields and deforestation. The equation estimated is

[Mathematical Expression Omitted], [12]

where  $Q$  is yield per acre and  $X$  includes  $[\Delta]$ ,  $w$ ,  $N$ , and  $[P]_{sub,F}$ .

#### IV. ESTIMATION AND TESTING

The empirical model, [9] and [12], is recursive in the sense of Greene (1997, 715-16). Assuming  $[\mu]_{sub,t}$  and  $[\epsilon]_{sub,t}$  to be independent for each  $t$ , applying OLS to each equation separately will yield consistent estimates. The data used are cross country. This is largely necessitated by the ownership security variable, which varies only at the level of countries. Country level aggregation has obvious disadvantages. Aggregate data on crop yields, changes in forest cover, and other factors poorly represent what is going on at the micro level. Also, certain potentially relevant variables are omitted in estimation due to lack of data, as noted in what follows, so specification bias may be a problem. These caveats should be kept in mind when interpreting the empirical results.

Forest cover,  $F$ , in the model, is defined as the share of land area covered by open or closed forests. Observations on forest cover in 1980 and 1985 are taken from the Food and Agriculture Organization (FAO 1988).(26) Countries were dropped from the sample if their initial forest cover was less than 5% of land area, or if their forests were more than 50% "open" as opposed to closed.(27) The empirical consequences of these sample restrictions are noted later. Agricultural yields are taken from World Resources Institute (1994) for two broad categories of crops, cereals, and roots and tubers, and are measured in kilograms per hectare. Annual yield data are available by country for 1970-1989.

Cross-country data on two environmental factors that might affect yields, a country's annual renewable water resources and the length of its coastline, both normalized by land area, were taken from World Resources Institute (1994). Population density is measured in persons-per-hectare. Cross-country data on agricultural wages and forest product prices are unavailable, so these terms were omitted.(28)

The measure of ownership risk is an index taken from Bohn and Deacon (1997). It was formed from an estimated investment function that relates investment rates in a cross-country panel to macroeconomic variables and political

attributes. The political attributes include measures of government instability and regime type, both of which are plausibly related to the effectiveness of the rule of law. See Bohn and Deacon (1997) for details.

The explanatory power of the ownership security index is evident from summary statistics not reported here. Countries were split into two groups, depending on whether their average investment rate was above or below the mean during 1970-1989. The ownership security index is significantly higher in the high investment group than the low investment group. In the high investment group, agricultural yields are roughly twice as high, and deforestation rates only about half as high, as in the low investment group. All of these differences are statistically significant at 2.5% or better. Clearly, ownership security, high agricultural yields, and low deforestation rates tend to be observed together.

Linear and log-log versions of the agricultural yield model, with random effects for continents, are shown in Table 1. The ownership security variable is significant and positive, as expected. Further, the magnitudes of these effects are large and very similar across models. A one standard deviation increase in the index is associated with a 32-35% increase in yields in all four cases.

Yields increase with population density as expected and the two environmental variables are significant in most models. "Year" is a time trend included to capture the effect of factors such as technology that vary only over time.(29) It is plausible that one omitted variable, the agricultural wage, is positively correlated with ownership security. If so, and if increased wages tend to result in higher yields, then the ownership security coefficient would be biased upward. Forest product prices, also omitted, are available for a small sample of countries and show no significant correlation with ownership security. Hence, specification bias does not seem an issue here.

TABLE 1

ESTIMATES OF THE AGRICULTURAL YIELD MODEL

| Dependent variable   | Cereal yield      |                  | Root and tuber yield |                 |
|----------------------|-------------------|------------------|----------------------|-----------------|
|                      | Linear            | Log-log          | Linear               | Log-log         |
| Ownership security   | .1562<br>(29.65)  | .7478<br>(27.22) | .9980<br>(25.95)     | .7410           |
| Population density   | .4584<br>(19.13)  | .1709<br>(11.69) | 1.3529<br>(15.62)    | .1489           |
| Coastline/area       | -.6646<br>(10.44) | -.0821<br>(3.35) | -4.2395<br>(8.98)    | -.2289          |
| Water resources/area | -4.2084<br>(1.68) | 7.0865<br>(4.91) | -81.1596<br>(3.05)   | -3.7451         |
| Year                 | .0386<br>(9.24)   | .0159<br>(7.75)  | .1593<br>(5.48)      | .0095<br>(4.25) |

|                   |        |        |         |        |
|-------------------|--------|--------|---------|--------|
| Constant          | -76.61 | -32.62 | -315.39 | -18.10 |
|                   | (9.25) | (8.04) | (5.48)  | (4.10) |
| [R.sup.2] overall | .42    | .44    | .31     | .34    |
| N                 | 2,215  | 2,215  | 2,159   | 2,159  |

Notes: t-statistics are in parentheses. Data are from 1970-1989.

In log-log specifications all variables except coastline/area and water resources/area are in natural logs.

The model was re-estimated with fixed effects for continents. This reduced the ownership security coefficients by 60-70%, but all remained highly significant. When the model was estimated with random effects for individual countries, rather than continents, the ownership security coefficient was sharply reduced, but remained highly significant in three models and marginally significant in the fourth. When estimated with fixed effects for countries, the ownership index became marginally significant at best. The reason ownership security tends to lose significance in models with country specific effects is that it does not vary much over time within countries, hence most of its explanatory power is captured by country effects. Obviously, if there are omitted variables that vary mainly across countries, their influence will contaminate the ownership security coefficient if they are correlated with that variable.

To shed light on this question the yield models were re-estimated with country-fixed effects, and with population and the time trend included as regressors, but without the security index. The fixed effects, which capture pure country-wise variation in yields, were then retrieved. These fixed effects were then used as dependent variables in cross-section regressions (118 observations each) with the following independent variables: country-wise average values for the security index, the coastline and water resource variables, and dummies for continents. The idea was to see to what degree ownership security explains the country-wise variation in yields, when forced to compete with other country-specific variables. Four regressions were estimated, linear and log forms for the two crops. These regressions explained 35-40% of the variation in country-fixed effects. Average ownership security is the only variable that was always significant, with t-statistics ranging from 5.3-6.0. On balance, it seems clear that the security index is not just picking up the influence of omitted environmental factors, or terms that vary primarily by continent.

TABLE 2

AGRICULTURAL YIELD MODEL CORRECTED FOR SERIAL CORRELATION

| Dependent variable | Cereal yield |         | Root and tuber yield |         |
|--------------------|--------------|---------|----------------------|---------|
|                    | Linear       | Log-log | Linear               | Log-log |
| Ownership security | .1707        | .4051   | 1.0416               | .1971   |
|                    | (15.20)      | (10.44) | (13.97)              | (6.17)  |
| Population density | .4863        | .1910   | 1.8139               | .1729   |
|                    | (10.03)      | (10.90) | (6.93)               | (8.04)  |

|                      |         |        |          |        |
|----------------------|---------|--------|----------|--------|
| Coastline/area       | -1.096  | -.0147 | -.8051   | -.0244 |
|                      | (5.19)  | (1.24) | (5.99)   | (3.23) |
| Water resources/area | -1.2019 | 1.7343 | -19.7146 | -.6905 |
|                      | (1.39)  | (3.13) | (3.58)   | (1.90) |
| Year                 | .0067   | .0040  | .0251    | .0010  |
|                      | (4.07)  | (3.83) | (2.47)   | (1.44) |
| Constant             | -13.04  | -7.98  | -49.61   | -1.71  |
|                      | (4.62)  | (3.88) | (2.47)   | (1.24) |
| Rho                  | .842    | .749   | .838     | .868   |
| N                    | 2,105   | 2,085  | 2,046    | 2,031  |

Notes: See Table 1.

The models in Table 1 exhibit serial correlation, with Durbin-Watson statistics below 0.22. To correct for this, a first order autocorrelation process, with a common correlation coefficient for all countries, was assumed and the usual autoregressive transformation was applied. A grid search identified a value of "rho" for each model that yielded a serial correlation coefficient in the transformed model below .001.

The resulting estimates are in Table 2. The ownership security coefficients are not appreciably changed in the linear specifications. They are reduced by 60 to 76% in log specifications, but remain highly significant. The magnitudes of ownership security effects were examined in the same fashion as before. For the linear estimates in Table 2, a one standard deviation increase in the index implies a 36% increase in yields of both cereals and roots and tubers. For the log models, a one standard deviation increase in the index raises yields by 17.6% for cereals and 8.6% for roots and tubers. Population density and most environmental terms also remain significant. Running these models with fixed effects for continents, or with fixed or random effects for countries, had effects similar to those reported for Table 1.

The forest cover model ([9]) was estimated using the cross-section data described earlier and Table 3 presents OLS results. The two agricultural yield variables were not entered together because they are highly correlated. Their coefficients are all positive, so higher agricultural yields are associated with greater forest cover. The yield effects are significant at 1% (cereals) and 6% (roots and tubers) in the log specifications, but only marginally significant in the linear specification. These findings provide modest confirmation for the historical observations. They are also consistent with empirical results from other studies. In a cross-section of Latin American countries, Southgate (1994) found increased crop yields to be significantly associated with [TABULAR DATA FOR TABLE 3 OMITTED] reduced acreage in agriculture. Panayotou and Sungsuwan (1994) report that forest cover responds positively to increased rice yields in provinces of Northeast Thailand.(30)

Ownership security is significant and positive in all models, as expected. Deleting agricultural yield variables from these models raises the ownership security coefficient by 25-30%, so the ownership security effect apparently operates partly through agricultural yields. The magnitudes of ownership security impacts were gauged by the same procedure used for yields. A one standard deviation increase in the index is associated with a 3134% decrease in the five-year deforestation rate in the linear specification and a 48-50% decrease in the log specification.(31) A one standard deviation increase in agricultural yields reduces deforestation rates by 18-28% percent in the four specifications.

Population density is insignificant in the linear specification. It is negative in the log specification, indicating that increased population density reduces forest cover, and significant in the model including cereal yields. Judging from the log specifications, where its coefficient can be interpreted as a short-run elasticity, the population effect is very small. According to equation [9] the forest stock coefficient should be negative and should indicate the fraction of distance moved toward long run equilibrium in the five-year period covered. Instead the forest stock coefficients are positive and very small. A plausible explanation for this is that the forest stock variable captures the effect of unmeasured environmental factors that are conducive to forest growth.

Re-estimating with random effects for continents had no appreciable effect on the coefficients. Including fixed effects for continents had only a slight effect on the ownership security index, but reduced the agricultural yield coefficients by 15-30%.<sup>(32)</sup>

## V. CONCLUSION

A somewhat stylized conclusion is that some societies enjoy high investment, stable democratic government, high crop yields, and low deforestation rates, while for those less fortunate, the opposite circumstances prevail. These associations are highly significant in contemporary data, and they emerge as common themes in historical accounts from the last three millennia. The present paper offers a simple explanation, based on security of ownership and consequent effects on incentives to invest and conserve.

The associated policy implications are novel. Advising those stuck in the worst of all worlds to mimic the investment, resource conservation, and agricultural practices of their better-off counterparts is unlikely to be fruitful. These unfortunates presumably are acting sensibly given their circumstances. Rather, it suggests that a more productive policy direction is to foster the development of stable, democratic government, and rule by law rather than by individuals or cliques.

Identifying actions that will have this effect is not a topic that economic research has pursued to date. The degree of political security a country enjoys presumably is endogenous, but the factors that determine it seem poorly understood at best. The unrest and repression that plague some countries may result from wealth inequality, population growth, and the dilution of resources, or cultural or religious factors. Understanding these factors, and the chain of causation that links them to investment and conservation incentives, should arguably be high on the research agenda of those who seek to affect the way forests are used, particularly in developing countries.

1 Some of the historical accounts presented here are also discussed in Deacon 1996.

2 World Resources Institute (1994), Tables 19.1 and 19.2.

3 Bawa and Dayanandan 1997.

4 Vandermeer (1996) claims that civil war in Nicaragua during the 1980s reduced forest destruction by discouraging road construction and logging activities. A referee points out that foraging by guerrilla bands depletes game, however, which may undermine seed dispersion and forest regeneration in the long run.

5 Reduced land clearing from increased yields is most plausible when demand for farm products is inelastic.

6 Pearce and Brown (1994, Table 1.11) summarize empirical results on the determinants of deforestation.

7 Thirgood (1981, 44). He reports that the Romans also believed that tree cover regulated water supply. In the fourth century B.C., Pliny referred to the occurrence of devastating torrents after mountain forests were cut and remarked that these had previously held and absorbed the rain.

8 Interestingly, Fernow (1913) reports that these groves were lost when instability was introduced, in the form of Christian fanatics who destroyed sacred groves in a campaign to obliterate pagan icons.

9 Moore (1957, pp. 66-68) also describes a system of rights governing access to water and minerals, with penalties for misuse, that extended to natural resources more generally: "rights to salt, salubrious fountains, sea water, fish in rivers and streams, and wild fruit were also locally regulated."

10 Destroying forests by fire also has been used as a gesture to dispute an enemy's claim to, or physical control of, an area of land. According to Thirgood (1981, 67), "The Syrians set fire to the forest in the 1940s in protest against the French Regime. In Cyprus, fire was an established form of resistance to forest regulation and control, and a much exploited method of terrorist escape during the campaign prior to independence. Subsequent communal unrest and

violence has been marked by outbreaks of widespread incendiarism, even extending to the use of military aircraft for this purpose."

11 An episode of wasteful revolutionary change from the Ottoman Empire is described by Reifenberg (1955, 104) and Thirgood (1981, 114). When a feudal land tenure system was abolished in the early 1800s, popular zeal for more egalitarian land assignments led to the Turkish Mesha system whereby parcels of land were reassigned among individuals by lot every one to three years. According to Reifenberg (1955, 104), "No terraces were maintained or constructed, no trees planted and no manure applied to the land." Thirgood (1981, 114) points out that the attempt at egalitarian assignment went even further, and caused additional degradation. "Individual narrow strips ran straight up the mountain sides, maintaining equity by including both valley and hill land [in each farmer's parcel]. In consequence, ploughing up and down slopes was customary," and this practice accelerated erosion.

12 The source for information in this section is Peluso (1992). Her primary thesis is that centralized control of forests that neglects the needs of populations who depend on forests most heavily has led to popular resistance to state control, and in cases, to popular violence against the forests, partly as a form of protest. While not disputing this claim, the following narrative does not dwell on it because the issue of primary interest here is different.

13 The remainder of this paragraph contains material from Peluso (1992, 101).

14 The hypothesis that deforestation is related to agricultural yields has been examined empirically. The relevant literature is briefly reviewed later.

15 Thirgood (1981) and Reifenberg (1955) make this point.

16 Stable government in a nomadic culture may well encourage investments in mobile assets. It probably would not lead to the conservation of forests, however. While the nomad's well-being is affected by the state of the environment in general, it is not tied to the condition of any specific site.

17 This information is from a passage in Thirgood (1981, 76). There is some evidence that nomadism can arise as a way of life as a consequence of insecure ownership of immobile assets. Thirgood (1981, 74) cites such an occurrence in Spain. Though traditionally a settled agricultural society, migratory grazing was for a time promoted by government as a deliberate policy. This occurred during the long struggle with the Moors, when mobile livestock came to be regarded as one of the few safe possessions.

18 Their analysis refers specifically to the Mayan state of Copan. They find that the naturally occurring pines were replaced by grasses and ferns in the upland forest zone, which seems to indicate increased clearing for agricultural land or wood. Deciduous trees were largely eliminated in the foothills in the Classic period. Abrams et al. (1996) also estimate overall wood consumption from estimates of population and per capita consumption of wood for cooking, heating, and housing needs. From this they conclude that forest clearing to meet these needs would have been extensive.

19 They conclude that deforestation was actually a cause of the collapse, rather than an effect. They argue that population growth led to extensive deforestation for fuel and farmland, pushing settlements into foothill zones. In their view, this led to soil erosion and a sharp decline in the region's agricultural viability, which eventually precipitated social and economic collapse. They argue forcefully (72) that the Maya fully understood the basic principles of erosion and its relation to agricultural practice, so the calamity was not due to ignorance. Rather, they believe the Maya were forced into "mismanagement" by the social stress of overpopulation. This interpretation begs one important question, however: Why did collapse occur in a fairly narrow time span throughout the widely separated settlements of the southern and western regions? It would seem an odd coincidence if local deforestation reached critical levels in all regions at roughly the same time.

20 Corroborating claims are reported in Ministry of Forests, Republic of Lithuania (1994, 20-21). Here it is reported that "during prolonged wars and periods of famine and plague the agricultural areas used to turn into forested ones again," evidently due to the decline in population pressure.

21 Empirical studies of this hypothesis are reviewed later.

22 Lopez (1997) finds that forest biomass serves as a productive input to shifting cultivation in Ghana. The consequences of extending the model to include biomass as an agricultural input are explained shortly.

23 If the opposite were true, that is, if agricultural demand were perfectly elastic, the same modeling framework would imply that greater capital intensity in agriculture reduces forest cover. This case would be relevant if crops grown

on converted forest land were primarily destined for export (or import substitution) rather than domestic subsistence. Greater capital intensity in agriculture would raise agricultural output without lowering food prices in this case, increasing agricultural land rents and causing conversion of forest land to agriculture. Strictly speaking, then, it is an empirical question whether more capital intensive agriculture will result in more or less forest conversion.

24 Thanks are due to a referee who pointed out that some such assumption is needed to obtain this result.

25 Considering forest biomass to be a productive agricultural input would not necessarily alter the form of this function, but would change its interpretation. Normalizing the total amount of land to unity and considering agriculture and forests to be the only two land uses implies that forest biomass would equal  $1 - A$ . Including  $1 - A$  as a separate variable in [3] would not alter the set of variables determining  $[R.sub.A]$ . In this case, however, increasing  $A$  would alter agricultural land rent in two ways with possibly different signs.

26 The FAO forest resource assessments covered 129 countries in 1980 and 84 countries in 1985. Data from an auxiliary source were used to extend the 1985 figures to the remaining countries, as explained in Deacon (1994). The FAO 1990 assessment based country forest cover numbers are projections from population growth and are inappropriate for the present purpose. See Cropper and Griffiths (1994).

27 Studying deforestation processes in a given period is meaningful only if a country's beginning stock of forest land is nontrivial, hence the 5% forest cover condition. Open forests include grasslands with tree cover as sparse as 10%, such as savanna or veldt regions of Africa, whereas closed forests have at least 25% tree crown cover and no continuous grass cover. The land use model applies to the accumulation and harvesting of forest biomass and the conversion of forest land to crops. It is not well suited to studying open forests, which can resemble range land with little woody biomass.

28 FAO data on roundwood prices are too sparse to incorporate in panel data regressions for crop yields.

29 Very similar estimates for the ownership security coefficient were obtained when the sample was redefined to exclude countries classified as "high income" by the World Bank (1992), which is roughly equivalent to deleting OECD nations and oil exporting countries. I also tried a specification that allows forest cover to serve as an agricultural input. When combined with the forest cover equation, this structure implies a reduced form equation for yields that includes all of the independent variables in Table I on the right-hand side, plus lagged forest cover. According to the agricultural input hypothesis, lagged forest cover should have the same sign in the reduced form as in the structural equation for yield. Thus, estimating the reduced form provides a test for its inclusion in the structural equation. Given the limited data available for forest cover, this reduced form model could only be estimated with a single cross-section. The reduced-form coefficients for lagged forest cover turned out to be generally insignificant, possibly because cross-country data are too coarse to allow the effect to be observed. Importantly, the coefficients on ownership security remained highly significant and did not differ much from those reported in Table 1.

30 Lombardini (1994) examines time series data for Thailand and finds a positive, though insignificant, correlation between forest cover and yields of cassava. Chahraborty (1995) examined the same question with data from Indian provinces and found it to be insignificant, allegedly because forests in India are not subject to free access.

31 A one standard deviation change in ownership security is associated with a five-year change in forest cover that amounts to 0.49% of forested land and approximately 0.30% of total land area.

32 Recall that the sample excludes countries with less than 5% percent forest cover in 1980 and countries in which forest are more than 50% open. Expanding the sample to include countries with as little as 1% forest cover in 1980 had only minor effects on the estimates. Likewise, including countries with forests as much as 80% open did not alter the estimates appreciably.

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