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Edward B. Barbier and J.C. Burgess

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EDWARD B. BARBIER and JOANNE C. BURGESS
Department of Environmental Economics and Environmental Management, University of York, Heslington, York YO1 5DD, UK

ABSTRACT. This paper uses panel analyses to estimate relationships for agricultural planted area and beef cattle numbers at the state level in Mexico during the period 1970–85, in order to determine the main factors affecting forest land conversion. Of the key policy variables, maize and fertilizer prices appear to be the main influences on the expansion of planted area, whereas beef prices and credit disbursement influence cattle numbers. Population growth also affects both livestock and agricultural activities, and income per capita is positively correlated with cattle expansion. These estimated relationships are used to examine the effects both of agricultural and livestock sectoral policy changes and of trade liberalization in Mexico resulting from the North American Free Trade Agreement (NAFTA). To avoid any unintended impacts of NAFTA on deforestation, it may be necessary for Mexico to make complementary investments in land improvements, especially for existing cultivation on rainfed land.

1. Introduction

Mexico's total forest area is 49.6 million hectares, covering 25.3 per cent of total land. Of this, around 24.1 million hectares are temperate forests concentrated in the south and southeast, and 25.5 million hectares are temperate forests located in the mountains running through the country. Of this total forest area, 34 million hectares is classified as potential production forest, with the rest being conservation, steep or degraded forest. Approximately 70 per cent of the land is owned by *ejidos* (communal land owners), 25 per cent by individuals and 5 per cent by Amerindian communities (World Bank, 1989).

Current estimates of the rate of deforestation in Mexico range from 400,000 to 1,500,000 hectares per year. All estimates agree that there is much more deforestation in the tropical than in the temperate areas. For example, Masera *et al.* (1992) indicate that 46 per cent of all forest clearance occurs in the tropical deciduous forests and a further 29 per cent in the

* This paper is based on a report prepared for the World Bank and the Government of Mexico (Barbier *et al.*, 1993). However, neither the World Bank nor the Government of Mexico nor any individuals associated with these two institutions are responsible for the views and analysis contained in this paper. Any faults or errors lie with the authors alone. We would like to thank our co-authors on the original report, Michael Collins and Colleen Clancy, as well as Luis Constantino and Augusta Molnar and anonymous reviewers on behalf of the Government of Mexico and the World Bank. We are also grateful to two anonymous referees for their comments on behalf of *Environment and Development Economics*.

tropical evergreen forests. The dominant impact on forest conversion has been made by the rapid expansion of livestock production and the demand for pasture land, particularly in tropical areas. In addition, an increase in land under rainfed agricultural production has been achieved mainly through forest conversion. In some areas, poorly managed timber extraction and forest fires have led to degradation and loss of forests. Road-building and timber extraction may also be the principal cause of 'opening up' new areas of forest for encroachment by other activities (Barbier *et al.*, 1993).

In this paper, we examine the extent to which government policies in the agricultural and livestock sectors have contributed to deforestation in Mexico. As previous studies of deforestation in tropical countries suggest that agricultural expansion and pasture formation are two major causes of forest conversion, we conduct a quantitative analysis of the underlying causes of deforestation in Mexico. Because of data limitations, however, the relationships influencing deforestation directly could not be examined. Instead, a more indirect approach is taken of using panel analyses to estimate relationships for agricultural planted area and beef cattle at the state level in Mexico over the 1970–85 period, which seem to be strongly correlated with loss of forest area. The results of the analysis of planted area and cattle expansion are then used to examine the likely implications for deforestation of specific government livestock and agricultural policy changes. Our policy analysis is combined with results from other studies to indicate the likely implications of the North American Free Trade Agreement (NAFTA) for deforestation in Mexico. Our paper concludes by examining the need for additional investment programmes and policies to complement policy liberalization in order to reconcile economic development with improved incentives for forest management and limiting deforestation.

2. Government agricultural and livestock policies and deforestation

Policies in Mexico's livestock and agricultural sectors affect deforestation by influencing the incentives to convert forest land for these economic activities, rather than maintain the forest for timber production, harvesting of non-timber products, tourism, watershed protection and other uses. Thus the comparative returns gained from converting forests to agricultural and livestock production are a major factor determining deforestation. In addition, the decision to augment 'existing' agricultural and pasture lands with new 'frontier' lands is affected by the comparative gains from converting forest lands. Finally, the expansion of frontier agricultural production and related activities such as livestock-raising has its own dynamics of 'rent-seeking' behaviour.

Consequently, if agricultural and livestock policies in Mexico were designed with the implications for deforestation taken into account, then the following incentive issues should be addressed:

- the optimal allocation of forest land among competing economic uses
- the comparative returns to existing versus frontier agricultural livestock land

- the 'rent-seeking' motivation for frontier agricultural and livestock land expansion.

Although our main focus is on agricultural and livestock policies that affect deforestation in Mexico, it is important to note that they are only one of a variety of economic policies that can potentially influence forest conversion and degradation. In general, sectoral policies have the most immediate and visible impacts on deforestation, but many broader fiscal, monetary and international policies can also have important effects (Repetto, 1988).

The agriculture, livestock and trade sectors have been the target of extensive intervention by the Government of Mexico (GoM) over recent decades. Interventions have taken the form of price controls, guarantee prices, input subsidies, trade restrictions and subsidized imports. GoM parastatals have also developed an important role in marketing, storage and processing. In recent years, the GoM has undertaken reforms in the agricultural and livestock sectors that have aimed to reduce the role of government in marketing, storage and processing. The objectives of these reforms are to improve the efficiency and competitiveness of these sectors and reduce the heavy financial burden of extensive intervention.

An important economic objective of the Mexican government since 1950 has been to keep the price of key industrial inputs and basic foods low at the consumer level in order to encourage industrial growth and economic development. In addition, the GoM has attempted to maintain high producer prices to bolster production in the agriculture and livestock sectors, with the particular objective of achieving agricultural self-sufficiency in basic grains and cereals. These two conflicting objectives have resulted in a complex array of policy interventions in the agriculture and livestock sectors over the past thirty to forty years. The GoM's pricing policies have included:

- establishing guaranteed producer prices (with or without state purchasing activity)
- administering prices for products that are purchased by semi-government agencies
- direct subsidies to private and parastatal processors.

In recent years, all commodity guarantee prices, except for maize and beans, have been eliminated as part of the liberalization drive in preparation for NAFTA. However, the GoM's objective of maintaining low urban food prices has often overridden the objective of higher producer prices; as a result, farmgate prices were allowed to decline in the late 1980s, particularly in real terms in the interests of eliminating the consumer–producer price differential. For sorghum, soybeans, rice and wheat, agreement prices are now in place. Except for credit subsidies, all input subsidies have been eliminated. Over the period 1983–7, agricultural and livestock lending represented on average 57 per cent and 28 per cent respectively of total lending by the main financial institutions, although lending to these sectors appears to have declined more recently (Barbier *et al.*, 1993).

3. Other relevant analyses of deforestation in developing countries

Several previous studies of analyses of deforestation in developing countries are worth reviewing briefly. For our purposes, it is relevant to distinguish between those studies that analyze the *direct* impacts on deforestation of key socio-economic and policy variables and those that analyze the *indirect* impacts, for example through the influence of these variables on the demand for agricultural land which is considered to be the main source of deforestation. We discuss studies that analyze the direct impacts of deforestation first.

Although there is an increasing number of case studies examining the factors behind tropical deforestation and agricultural frontier expansion, there have been few attempts to explore these linkages through statistical analysis. Those that have been conducted are generally fairly aggregate and regressed on a cross-country level.[1] One such analysis by Palo *et al.* (1987) for seventy-two tropical forest countries identified a strong link between tropical deforestation and population density, population growth and increased food production. A study by Capistrano (1994) examined the influence of international and domestic macroeconomic factors on tropical deforestation.[2] The econometric analysis indicates the role of high agricultural export prices in inducing agricultural expansion and forest-clearing, as well as the influence of domestic structural adjustment policies, such as exchange rate devaluation and increased debt-servicing ratios. A more recent statistical analysis by Burgess (1993) of fifty-three tropical countries supports the hypothesis that population pressure and industrial roundwood production are positively associated with forest clearance in the tropics over the period 1980–5, although the former is much more significant in its impact. Economic development, as represented by rising per capita GNP, and improvements in agricultural yields reduce forest-clearing. However, the analysis also indicates that countries whose forests are small relative to total area are depleting these forests at a high rate.

In recent years, some important cross-sectional analyses of the causes of deforestation have been conducted for specific Latin American countries. For example, Reis and Margulis (1993) analyze the relationship between the spatial density of major economic activities and the share of deforested areas across 165 municipalities in the Brazilian Amazon. The model examines the densities of population, cattle, logging, crop area and roads as major factors in the deforestation process. The highest value of the elasticity of deforestation is 0.40 in relation to the density of crop areas, although elasticities for road density and population density are also rela-

[1] For a more detailed review of some of the following and other studies on the causes of deforestation, see Brown and Pearce (1994) and Burgess (1995).

[2] Capistrano (1994) uses changes in timber production forest area as a proxy for total deforestation. Thus the analytical results are more relevant to the deforestation of tropical timber production forests than to overall tropical deforestation. For an in-depth review of the impact of logging relative to other factors influencing tropical deforestation, see Amelung and Diehl (1992), Burgess (1993, 1995) and Barbier *et al.* (1995a).

tively high. However, the elasticity of deforestation with respect to cattle density is less than one third of the value for crop area, and the coefficient on logging density is not statistically significant. With respect to cattle-raising, the authors argue that although one interpretation may be that its role in deforestation is grossly overstated, it is the process of cattle-raising following crop expansion that has made forest conversion irreversible in the Brazilian Amazon.[3]

Southgate *et al.* (1989) examine the causes of agricultural colonization and deforestation in eastern Ecuador in the early 1980s. They analyze the statistical significance of rural population pressure, local demand for agricultural commodities, infrastructure development and tenure security as factors explaining forest land clearing across twenty cantons. First, the area's agricultural labour force, a proxy for rural population pressure, is regressed against the factors thought to determine agricultural rents: urban population (increased demand), soil quality (productivity constraint) and roads (market accessibility and opening forest areas). Second, the extent of land clearing is regressed on the rural population pressure variable and an index of relative tenure security. The results of the analysis support the hypothesis that the incentive to capture agricultural rents is the main driving force behind forest conversion, and is further induced by tenure insecurity. The study emphasizes the role of population pressure in encouraging deforestation, directly through an increasing rural labour force and indirectly through rising urban food demand, but also emphasizes the role of misguided government policies regarding land tenure arrangements and extension of the road network into forested areas.

In Mexico, an attempt at a cross-sectional analysis of forest cover and agricultural intensity for 434 rural 'productive' units (e.g. holding by *ejidatarios* and others) was conducted by Muñoz (1992). The basic source of land use data was the 1980 *Censo Agropecuario y Ejidal* (Rural Census). The independent variables explaining the changes in the percentage of land area per holding under forest or agriculture included climatic conditions, road density, population density, size of plot, type of property and measures of rural poverty. The results of the analysis indicate, as expected in a logit model, that explanatory variables have opposite effects on the two types of land use. Road and population density have an important influence on the probability of finding forest cover as opposed to agriculture on a plot; the size of the plot has a positive effect on forest cover but not on agricultural area; *ejidatarios* are more likely to have agriculture than forest cover on their plots; and in humid as opposed to dry regions the probability is higher of having forest rather than agricultural cover. Unfortunately, this promising analysis by Muñoz (1992) is marred by some

[3] The results of the model may be affected, unfortunately, by collinearity problems between some independent variables, which the authors freely admit. See Reis and Guzmán (1994) for an updated analysis.

significant flaws in the logit analysis, which cast doubt on some of the statistical results.[4]

As noted, the difficulty in obtaining data on forest cover or deforestation rates often leads to the analysis of deforestation indirectly through examining the factors explaining expansion of agriculture or other conversion activities. For example, many of the direct deforestation analyses have pointed to expansion of cropping and possibly livestock production as major factors underlying deforestation.

For example, a recent study in Thailand highlights the complex linkages between agricultural crop prices, the relative returns from different crops and the demand for land (Phantumvanit and Panayotou, 1990). In Thailand, approximately 40 per cent of the increase in cultivated land in recent years is accounted for by converted forest land. The statistical analysis indicates that the most important factors affecting the demand for cropland, and thus forest conversion, appear to be population growth followed by non-agricultural returns, although agricultural pricing also has a significant influence.[5] Higher aggregate real prices may have a slightly positive influence on the demand for cropland and thus increased forest clearing; however, this direct effect may be counteracted by the indirect impact of higher agricultural prices in raising the productivity of existing land and increasing the cultivation of previously idle land, thus reducing the demand for new land for forest-clearing. Changes in relative prices also influence the demand for new cropland by affecting the relative profitability of land-saving as opposed to land-extensive cropping systems. Finally, the relative returns to land-saving cropping systems can also be affected by the relative costs of inputs (e.g. fertilizer, seed, credit, irrigation, agrochemicals) where these differ between land-saving and land-extensive systems. Presumably, then, the relative prices of crops to inputs would also affect the comparative returns of land-saving as opposed to land-extensive systems.

Comparative analysis of twenty-four Latin American countries also

[4] For example, the analysis uses three dummy variables and no constant regression. In addition, it is not clear whether the dependent variable for the percentage of land under forest area (FORS) is expressed as proportion or in logarithm form (e.g. LN (FORS)). The latter is more appropriate for a logit analysis. However, of most concern is that each regression appears to include a constant equal to 1 as an explanatory variable. If this is the case, then the logit analysis is misrepresented. The resulting estimation is FORS or $LN(FORS) = \beta_0 * 1 + \beta X$, where βX represents the other coefficients and respective explanatory variables of the regression. As a consequence, a near-singular matrix may be created by the regression, which would explain why all coefficients display confidence levels approaching unity. An alternative and more conventional specification of the logit regression would be $LN(FORS) - LN(1 - FORS) = \beta X$, with the constant generated by the regression as usual. For an application to tropical deforestation, see Barbier *et al.* (1995b).

[5] Although the goodness of fit of the statistical results is impressive, they appear to be achieved through combining the log-linear model with the use of higher-order autogressive terms to correct for serial correlation, which generally tends to improve the explanatory power of such models. For a more recent analysis of the causes of deforestation in northeast Thailand see Panayotou and Sungsuwan (1994).

highlights the strong but indirect relationship between population pressure and frontier expansion and thus forest clearance—increasing numbers of urban consumers raise the demand for domestic production and hence for agricultural land—and the countervailing role of increased agricultural productivity and yield growth in slowing agricultural expansion (Southgate, 1991). An important addition of this analysis is the inclusion of a land constraint variable (for countries with a low potential agricultural land availability). Where there is little appropriate land available for conversion, the growth in arable land, and thereby forest clearance, is significantly reduced.

4. Policy analysis of the incentives to deforest in Mexico

The analyses of deforestation discussed in the previous section suggest that changes in government policies are likely to affect deforestation by influencing comparative economic returns to different economic activities on forest land and by affecting the comparative returns to these activities on existing as opposed to converted forest, or 'frontier' land. In addition, sectoral policies can stimulate or deter the rent-seeking motivation for continual frontier agricultural and livestock land expansion.

In practice, however, it is very difficult to determine the overall effects of policy changes on deforestation, as it is likely that a given policy change will have both positive and negative impacts on forest conversion and degradation. For example, in Mexico agricultural and livestock expansion are the activities thought to be most responsible for deforestation. As indicated above, the most powerful incentive effect of policy changes will be on the comparative returns of agricultural and livestock production. In the case of product and input price changes, the implications for returns and production can be very direct and immediate. By affecting the returns from agricultural and livestock activities, price changes influence the choice of crop and livestock inputs and outputs, production systems, land investments and the scale and extent of production. These production choices in turn determine the rate and scale of resource use, including forest land conversion, and investments in land improvements and management. However, these latter implications are clearly second-order and indirect. Thus, although increasing agricultural and livestock prices may translate into higher returns from increased production, the resulting expansion of output does not necessarily lead to greater forest conversion; the way in which the extra cultivation is carried out is the key factor.[6]

In Mexico, an important consideration is that the expansion of planted agriculture and pasture land in recent years may have been achieved not only by the conversion of forest land but also by bringing previously unused or fallow land into cultivation. Almost one quarter of agricultural land is idle, perhaps proportionately more on larger farms. Any aggregate increase in production from improved returns to agriculture could come from either increased production on existing planted land, new production

[6] For further discussion and examples, see Barbier and Burgess (1992) and the case studies cited in the previous section. See also section 5 for analysis of the factors determining the demand for agricultural land in Mexico.

on previously fallow land or conversion of additional forest land to agriculture. The net effects on deforestation are not always readily apparent.

The situation is illustrated in Figure 1. Total agricultural land consists of existing agricultural land and any additional frontier agricultural land, if it is worth bringing the latter into production through conversion of forest land. Thus the total land available for cultivation is OD + OG. However, not all of the convertible forest land, OG, may be worth cultivating. For example, if in the extreme case the returns to cultivating convertible forest land were zero, then existing agricultural land area OD would represent the total agricultural land in production. However, suppose, as actually shown in Figure 1, curve AH depicts the returns per hectare (ha) on existing agricultural land, and curve BG the returns that could be earned on convertible forest land if it were brought into production. Thus, area OC of existing land is under production, and the remaining CF ha of existing agricultural land is fallow. Additional agricultural production would therefore come from area CG of convertible forest land on the frontier. Note that DF ha of fallow land would be idled because they are economically unproductive. However, CD ha would be idled because they could not compete with the returns from convertible forest land.

The impacts of agricultural frontier expansion on deforestation could be reduced by a policy that raises the returns on existing agricultural land so as to bring previously idle land into production as a substitute for additional production from convertible forest land. As shown in Figure 1, suppose that such a policy exists, e.g. targeted land or irrigation improve-

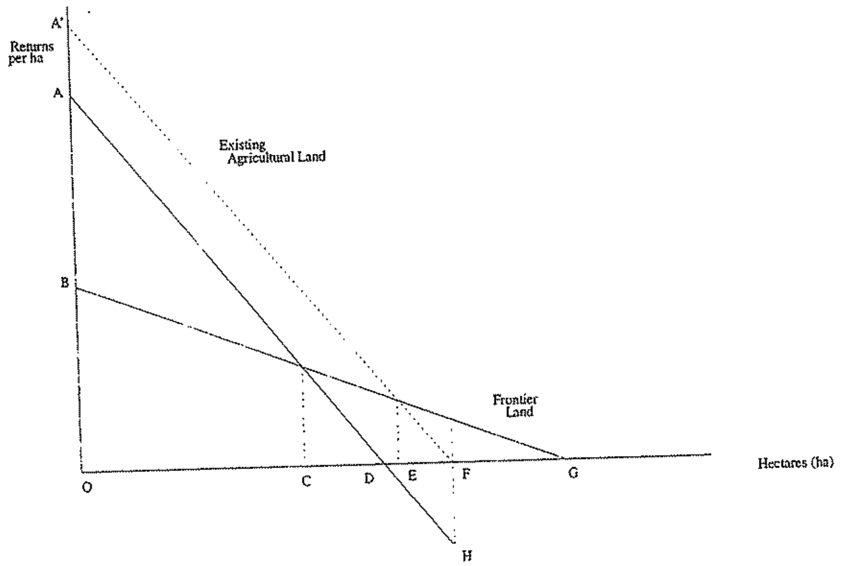

Figure 1. *The comparative returns on existing and frontier land. As the returns to existing agricultural land increase (from AH to A'F), the amount of fallow land decreases (from CF to EF) and less land is exploited on the frontier (from CG to EG).*

ments on existing agricultural land. Then the comparative returns on this land would increase, from AH to A′F. As a result, previously idled land becomes more attractive to cultivate, and the area of fallow land falls to EF. In addition, the comparative returns to convertible forest land are less attractive, and consequently the forest area that would be converted falls to EG ha.[7]

In practice, however, most agricultural and livestock policies are difficult to 'target' as depicted in Figure 1. Most sectoral policies in Mexico have had the overall objective of raising production of key agricultural and livestock products and are thus indiscriminate in terms of whether this increased production comes from existing or frontier agricultural land. Although it is not shown in Figure 1, it is easy to indicate with this diagram that if the returns to both existing and convertible forest land increase (i.e., curves AH and BG both shift out) then there will be little change in the amount of forest land converted to agriculture. In fact, as discussed throughout this paper, many agricultural, livestock and other economic policies in Mexico may actually be encouraging deforestation by making the returns to frontier agriculture more attractive.

Policy analysis is further complicated by consideration of the comparative returns between agriculture and other forest land uses on the frontier. This situation is illustrated in Figure 2. For simplification, it is assumed that there are three competing uses of forest land: forestry, agricultural and livestock production. Forestry yields the highest returns (curve AE), but only on a limited amount of forest land. The amount of forest land retained for permanent wood production is OD ha. Where agriculture yields higher returns (curve BG), forest land is converted to agriculture. This amounts to DF ha. However, some forest land will yield higher returns under livestock production (curve CH), and thus FH ha of forests should be converted to pasture land.

An increase in the comparative returns to agriculture on forest lands (from BG to B′G′) could lead to agricultural expansion at the expense of permanent forest production (OD decreases), and substitution of livestock for agricultural production on the frontier (FH decreases). The net effect on deforestation depends on the comparative returns to forestry and agriculture, and not on the substitution of agricultural for livestock production on frontier land. The latter effect is simply the substitution of one conversion activity for another. Moreover, there is an overall welfare gain as the returns to converted forest land in general are increased. If property rights are well defined, access to additional areas of unexploited forests is costly and the returns to the converted land can be maintained, then farmers may

[7] Alternatively, correcting the market failures and policy distortions that effectively 'subsidize' the returns to convertible forest land and thus contribute to excessive deforestation would be represented by a decrease in the curve BG in Figure 1. This 'ideal' policy would also increase the comparative returns to existing agricultural land, thus leading to a substitution of idle for convertible forest land. However, as a maximum of CD hectares could be cultivated economically, production and efficiency losses would occur if the comparative returns to convertible forest land on the frontier fell sharply.

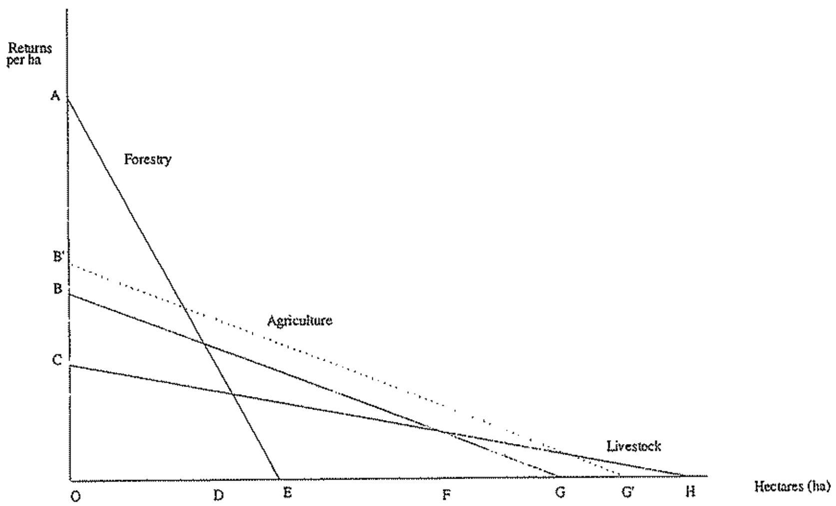

Figure 2. *The comparative returns to different forest land uses. An increase in the comparative returns to agriculture on forest lands (from BG to B'G') could lead to agricultural expansion at the expense of permanent forest production (OD decreases) and substitution from livestock to agricultural production on the frontier (FH decreases). The net effect on deforestation depends on the comparative returns to forestry and agriculture only.*

not have the incentive to expand frontier cultivation further through 'rent-seeking' behaviour. Finally, if as shown in Figure 2 the returns to forestry are fairly high on land allocated to permanent forest production, then very little net additional deforestation will occur through substituting agricultural for forestry activities. The increased agricultural activity would largely be confined to forest land demarcated for conversion anyway.[8]

Figure 2 again clearly represents an ideal situation. Forestry, agriculture and livestock production are being influenced by a variety of policies simultaneously. It is difficult to determine the implications for the comparative returns of the three frontier activities, let alone the net effects on forest land conversion. The conditions determining the extent to which these different forest land uses compete with each other also vary significantly across the different forest regions of Mexico. Finally, the basic legal and regulatory framework affecting forestry, agricultural and livestock production in Mexico is currently undergoing major revision, which could have important implications for rent-seeking motivation in frontier forest land exploitation.

The analysis of comparative returns indicated by Figures 1 and 2 formed the conceptual basis of our empirical analysis of the incentives to deforest in Mexico. Unfortunately, we were prevented from estimating the re-

[8] Although not shown in Figure 2, presumably some timber harvesting would also occur on forest land converted to agricultural and livestock production.

lationships represented in Figures 1 and 2 directly, by a number of limitations.

In Mexico, time series data on tropical forest area and conversion trends are not yet sufficiently disaggregated or complete to conduct a *direct* analysis of deforestation. Yet there is substantial evidence to suggest that forest clearance for agricultural and livestock production is prevalent throughout Mexico. However, data on total agricultural area and pastoral land are also insufficient and unreliable. In particular, it was impossible to disaggregate the data between existing and frontier livestock and agricultural activities, as suggested by Figure 1.

Nevertheless, it is possible to conduct an *indirect* analysis of the factors influencing forest conversion in Mexico, by focusing on the increases in agricultural planted area and beef cattle numbers disaggregated by state and over time. The key assumption is that increasing agricultural expansion and livestock grazing have been the principal *proximate* causes of deforestation in Mexico over the previous two and half decades, and the factors determining agricultural and livestock expansion are thus the *underlying* causes of forest conversion and degradation. Over the period 1970–91, as forest area has fallen, agricultural planted area and cattle numbers have increased, although the latter have started to decline in recent years.[9] This would again support the hypothesis that agricultural and livestock expansion are proximate factors influencing deforestation in Mexico. However, it is important to stress that this assumption remains a hypothesis, which cannot at this time be statistically proven. More importantly, the exact magnitudes of the relationships between increasing agricultural and livestock expansion and deforestation cannot be reliably estimated.

By taking this (untested) hypothesis as our starting-point, it is possible to focus on the underlying causes of forest conversion by analyzing the factors behind increases in agricultural planted area and beef cattle head in Mexico. With regard to the latter, assuming a zero rate of return to unconverted forest, Figure 2 suggests that not only will increasing returns to frontier agriculture lead to forest conversion but also, if agricultural and livestock production are competing activities on the frontier, then an increase in the returns from livestock production will negatively affect frontier agricultural land expansion. Equally, an increase in the returns from agriculture will reduce the demand for livestock expansion on the frontier. In the following analysis we were able to examine this hypothesis that agricultural and livestock production are competing activities on the frontier, by including livestock and maize prices in the regressions for planted agricultural area and beef cattle numbers respectively.

[9] As the decline in more recent years is substantial and registered across all states, it could be due to calculation errors or statistical adjustments. However, this has proved difficult to verify. Any such adjustments or errors may have introduced an element of bias in the subsequent analysis of beef cattle head discussed below.

5. Analysis of planted agricultural area

There is strong evidence to suggest that the increase in land under agricultural production in Mexico over recent decades has been achieved mainly through the conversion of forests, particularly tropical forests. Moreover, a high proportion of agricultural land—almost one quarter—is idle or fallow. This would suggest that the planted area is expanded through bringing additional land into cultivation rather than utilizing the existing stock of arable land. The extent to which planted area increases in each state should therefore provide a good indicator of forest land conversion for agriculture.

The panel analysis of longitudinal data for planted agricultural area was conducted across the thirty-one states of Mexico plus the *Distrito Federal* (Federal District), over the 1970, 1980 and 1985 time periods. Several explanatory variables were examined, including real guaranteed maize prices, real fertilizer prices, income per capita, population levels, real rural wages and road density. In addition, real livestock prices were included, to determine the extent to which this variable influences the agricultural land expansion. Details of the relevant variables and sources are indicated in Table 1.

Discussion of the regression procedure, results and basic statistical diagnostic tests are included in the Appendix at the end of this paper. A random-effects error component model utilizing feasible generalized least squares (FGLS) proved to be the preferred consistent and efficient estimator. The results of the FGLS regression for both 'with' and 'without'

Table 1. *Definition and sources of data for analysis of agriculture area planted and numbers of livestock*

Variable	*Definition and data sources*
MAAP	Agriculture area planted (state level, '000 ha). Agricultural area planted data derived from SARH (1988).
MLH	Livestock head (state level, '000 head). Livestock numbers derived from SARH (1988) and INEGI (1992).
MGMFP	Ratio of guaranteed maize prices to fertilizer prices (national level, constant MEX$/ton). Maize and fertilizer price data derived from SARH (1988).
MLP	Real livestock prices (state level, constant MEX$/kg to constant MEX$). Livestock price data derived from SARH (1988) and Robles (1992).
MYC	Income per capita (state level, constant MEX$/population). Income data derived from SARH (1988). Population data derived from SARH (1988) and INEGI/SPP (nd).
MP	Population (state level, number). Population data derived from SARH (1988) and INEGI/SPP (nd).
MGMP	Real guaranteed maize prices (national level, constant MEX$/ton). Maize price data derived from SARH (1988).
MRD	Road density (state level, km/ha). Road and state area data derived from SARH (1988).
MC	Credit (state level, constant MEX$ mn). Credit represented by loans made by FIRA and BANRURAL; data derived from SARH (1988).

livestock prices are depicted in Table A1. Livestock prices prove to be highly insignificant in the regression. This suggests that the hypothesis that livestock prices should influence planted agricultural area is rejected by the model, and thus the FGLS regression version without livestock prices shown in Table A1a is preferred.

As Table A1a indicates, the only significant explanatory variables in the FGLS regression are relative maize/fertilizer prices and population. Real income per capita and road density are not significant. Table 2a summarizes the resulting elasticities for the two significant variables.

Relative maize/fertilizer prices have the larger impact on agricultural planted area. A 1 per cent increase in this price ratio will lead to a 0.32 per cent change in planted area. As this is an output/input price ratio, it is an approximation of the returns to planting maize and related crops. In addition, any change in these returns would have an important influence on the allocation of forest land among competing uses, the comparative returns to existing versus frontier agricultural land, and the 'rent-seeking' motivation for frontier agricultural expansion. Thus, one would expect that an increase in the relative returns from maize would have an important influence on the total agricultural area planted across Mexico, and therefore possibly on forest clearance.

The other significant variable, population, should also be associated with increased planted agricultural area. There are essentially two reasons. First, a higher population could mean that the agricultural sector has to absorb more workers and subsistence farm families, thus putting more pressure on the land base, including forest. Second, higher populations create this pressure indirectly through demand for food, fuel, fodder and other consumptive goods. In our analysis, a 1 per cent increase in state populations leads to a 0.23 per cent rise in agricultural area planted.

A surprising result of the analysis is that road density is not significant, despite the fact that road-building in Latin America is generally con-

Table 2. *Calculation of elasticities for planted agricultural area and beef cattle*

a. Planted agricultural area ('000 ha)

Variable	*Coefficient*	*Mean*	*Elasticity*
MAAP		532.84	
MGMFP	167.49	1.0267	0.3227
MP	0.000077	1,986,278	0.2882

b. Beef cattle ('000 head)

Variable	*Coefficient*	*Mean*	*Elasticity*
MLH		958.05	
MLP	43.425	9.2548	0.4195
MP	0.000051	1,986,278	0.1062
MC	0.3765	347.06	0.1364
MYC	0.00865	10,280.77	0.0928

Source: FGLS regressions in Appendix Tables A1a and A2a. Only the significant variables from these regressions are included.
Note: For variable definitions, see Table 1.

sidered to be associated with the opening up of forest area for agricultural expansion (Reis and Margulis, 1993; Mahar and Schneider, 1994). However, a distinction should be made between an increase in the *road network* as represented by the absolute number of road kilometres built, and *road density* as represented by the number of road kilometres built per square kilometre of total state area. Deforestation usually results from the extension of the road network into previously remote areas. Thus, as discovered by Southgate (1991), the absolute number of road kilometres built can be a significant factor in land-clearing. However, increasing road density at the state level may actually reflect rapid urbanization and modern-sector development. As argued above, this would reduce pressures on agricultural land expansion and forest-clearing. The inconclusiveness of our analysis may be due to a combination of these two effects.

To summarize, if increasing agricultural planted area is correlated with deforestation, then the results of our analysis reveal some important factors underlying forest conversion in Mexico. Increasing the relative returns to maize production, as reflected in the maize price ratio, leads to further pressure on the forest. Rising populations at the state level also have a positive impact on forest conversion. However, neither income per capita nor road density seems to affect significantly agricultural planted area. The hypothesis that livestock prices should influence planted agricultural area is also rejected by the model.

6. Analysis of beef cattle head

Beef cattle production is a highly land-extensive process. There are limits to the number of cattle that can be grazed on a given plot of pasture land before it is irrevocably degraded. Degradation of pasture land, in any case, can lead to the abandonment of that land in favour of new pasture formation. Moreover, legally each farmer is restricted to a maximum of 500 head of cattle (Maddison *et al.*, 1992). Consequently, an increasing number of cattle in a region or state is an indication that new farms and pastures are being established. Increases in the number of beef cattle per state are therefore a good approximation of the extent of pasture land expansion in Mexico.

Thus an additional panel analysis of longitudinal data for beef cattle numbers (i.e. livestock head) was conducted across the thirty-one states of Mexico plus the Federal District, over the 1970, 1980 and 1985 time periods. Several explanatory variables were examined, including real beef prices, income per capita, population levels, real rural wages, road density and real credit disbursement. Real guaranteed maize prices were also included, to determine how far the expansion in beef numbers is explained by this variable. Details of the relevant variables and sources are indicated in Table 1.

As discussed in the Appendix, the random-effects error component model utilizing FGLS again proved to be the preferred consistent and efficient estimator. The results of the FGLS regression both with and without maize prices are depicted in Table A2. Maize prices prove to be highly insignificant in the regression. This suggests that the hypothesis that maize prices influence livestock numbers is rejected by the model, and thus the

FGLS regression version without maize price shown in Table A2a is preferred.

Table A2a shows that livestock prices, population, credit and income per capita are all significant in explaining beef cattle demand. Road density is the only variable that is not significant. Table 2b summarizes the resulting elasticities.

Livestock prices have the largest impact on the number of beef cattle per state. As expected, the relationship is positive. A 1 per cent rise in these prices leads to a 0.42 per cent increase in the number of cattle. If it is assumed that increasing livestock prices are correlated with increasing returns to cattle-raising, then rising prices and thus greater returns lead to greater cattle herd expansion and conversion of forests through pasture formation.

An increase in real credit disbursement also leads to greater beef cattle numbers at the state level. Over the 1970–85 period, much credit was extended to the livestock sector, and these loans were heavily subsidized. Thus, one would expect that higher cattle numbers and pasture formation would result from an increase in credit disbursement. The analysis indicates that a 1 per cent rise in loans increases head of beef cattle by 0.14 per cent.

As in the case of planted agricultural area expansion, an increase in population at the state level is also a significant factor in determining greater cattle numbers. A 1 per cent rise in population causes cattle numbers to increase by 0.11 per cent. Like the growth in a planted area, a rise in population means more direct pressure on the land base, including the forest, through the establishment of new farms and ranching operations, and more indirect pressure through increased demand for beef and other livestock products.

Income per capita also appears to be positively correlated with greater livestock numbers over the 1970–85 period. A 1 per cent increase in per capita income at the state level leads to a 0.09 per cent increase in beef cattle. There may be two reasons for this positive relationship. Cattle-raising is generally a commercial activity that may be associated with a state's agricultural development from subsistence to commercial agricultural activities. In general, one would expect a state's average per capita income to increase with such agricultural developments. In addition, rising per capita income is associated with increasing demand for meat, which may be reflected in increased cattle numbers.

Finally, as in the case of planted agricultural area, a surprising outcome of the analysis of the demand for livestock head is that road density is not a significant variable. It is assumed that this is for the same reasons discussed above in section 5.

To summarize, if increasing beef cattle numbers in Mexico are correlated with forest conversion to pasture, then several factors appear to play an important role. The most significant appears to be the returns to cattle operations, as reflected in the price of beef. Increasing credit disbursements, population levels and, to a lesser extent, rising income per capita are also important factors underlying forest conversion for cattle-raising. However, road density does not seem to be significant in affecting cattle numbers. The hypothesis that maize prices influence planted agricultural area is also rejected by the model. Together with the similar result for the effect of livestock prices on agricultural area planted, this suggests that over the 1970–85 period livestock production and agricultural expansion were not competing for land on the forest frontier in states across Mexico. Nevertheless, as the overall demand for land in Mexico can be expected to increase, especially with rising population, the result may be greater competition between livestock and agricultural activities for frontier land.

7. Analysis of specific agricultural and livestock policies

The major policies affecting Mexico's agricultural and livestock sectors are described in section 2. In recent years, these policies have been undergoing major changes as part of the transition to a more outward development strategy and as the GoM has attempted to reduce government expenditures. Much of the economic reform in the direction of increased liberalization has been part of the transition to Mexico's participation in NAFTA. As a consequence, some sub-sectors in agriculture and livestock have been undergoing reduction in subsidies and other support programmes, in order to improve competitiveness.

As discussed above, analyzing the impacts of these sectoral policy changes on deforestation in Mexico poses many problems because of complex linkages. A further difficulty is that the process of internal economic reform and liberalization for many sub-sectors (e.g. maize) in Mexico is slow and only just beginning. However, in the previous sections the analyses of the demand for agricultural land and cattle expansion indicated that certain policy variables may have important effects on forest conversion. We therefore analyze in this section the effect of policy changes on these variables, which are:

- maize and fertilizer prices as determinants of the returns to agriculture and thus expansion of planted area
- beef prices as a determinant of the returns to cattle-raising and thus expansion of livestock numbers
- rural credit disbursements as a determinant of the returns to cattle-raising.

We utilize the statistical analyses and results derived in sections 5 and 6 as the starting-point in examining these relationships.

Maize prices

Maize prices in Mexico are beginning to be liberalized as part of the drive towards Mexico's membership of NAFTA. Maize is a key agricultural sub-sector in Mexico since it is the main stable crop and its cultivation provides much rural employment. GoM maize policies have essentially maintained a divergence between producer and consumer prices, with the former generally above and the latter generally below the border-equivalent international price for maize. Given the strategic importance of the crop, efforts to liberalize the maize sub-sector are proceeding slowly.

In section 8, we explore in more detail the implications of liberalization of the maize sub-sector for overall rural development and deforestation. As background to that discussion, we focus here on the potential effects of price changes for maize on the return to its cultivation and thus forest conversion. As discussed above, the latter impacts are the result of changing maize prices affecting the comparative returns to existing as opposed to 'frontier' agricultural land, the comparative returns to maize cultivation on forest land and the motivation for 'rent-seeking' through extending cultivation and forest conversion. Because maize accounts for over half the crop area harvested in Mexico, these effects of changing maize prices could be extremely important in determining forest conversion.

Unfortunately, the analysis of the expansion in planted agricultural area in Mexico over the period 1970–85 could not be disaggregated sufficiently to distinguish between new production on 'idle' land and new production on converted forest land (see sections 4 and 5 and the Appendix). Rather, the analysis shows only the aggregate effect on planted area of increases in the maize/fertilizer price ratio. Not all of the increase in planted area would come from forest conversion, but without further information it is difficult to determine this proportion.

Table 2 indicates that an increase in the maize/fertilizer price ratio, our proxy for returns to agricultural and particularly annual crop production, has a strong and positive impact on the area of land planted in Mexico. In Table 3a, the elasticities estimated in our model are used to calculate the potential impact of various increases in maize prices on agricultural planted area, using 1990 values as the base case reference point.[10] For example, a 10 per cent decrease in maize prices would lead to a 3.23 per cent fall in area planted. Such 'instantaneous' effects, particularly for large price movements, represent approximate 'order-of-magnitude' indicators rather than predictors of actual responses.[11]

Due to the GoM policy of supporting the rural producer price well above the world price of maize, liberalization of the maize market would cause the price to fall considerably. For example, using 1989 values as their base case reference, Levy and van Wijnbergen (1992a) suggest that 'instantaneous' liberalization would lead to a 50 per cent reduction in the rural producer price of maize (see also section 8).

As indicated in Table 3a, such a large price response to 'instantaneous' liberalization would translate into a major impact on agricultural area planted (i.e. a 16 per cent decline as an 'order of magnitude'). As discussed further in section 8, the resulting impacts on the entire rural sector, particularly employment of subsistence and landless workers, would be severe. Moreover, a general fall in the price of maize would not conform to the 'ideal' policy described above, as it would affect indiscriminately the returns to agricultural production on both existing and frontier agricultural land. That is, there is little incentive for substituting previously idled land for converted forest land.

The effects of falling producer prices on the returns to maize cultivation

[10] In Tables 3 and 4, because real values are expressed in constant 1980 prices, the unit of account is 'old' rather than 'new' pesos.

[11] Moreover, as indicated in Table 2, these elasticities were calculated around the means of the panel data and small (per unit) effects. Applying these elasticities to much larger changes will invariably increase inaccuracy.

Table 3. *Effects of changes in key policy variables on planted agricultural area*

a. Maize prices (nominal 1990 MEX$618,000/ton)

		Percentage change		
Effect on:	*Base case value*	*–10%*	*–50%*	*–70%*
Real maize prices (MEX$/ton)	3,471	–347	–1,736	–2,430
Maize/fertilizer price ratio	1.31	–0.13	–0.66	–0.92
Planted area ('000 ha)	19,261	–622	–3,108	–4,351
(% change)		(–3.23%)	(–16.14%)	(–22.59%)

b. Fertilizer prices (nominal 1990 MEX$471,000/ton)

		Percentage change		
Effect on:	*Base case value*	*10%*	*50%*	*70%*
Real fertilizer prices (MEX$/ton)	2,645	265	1,323	1,852
Maize/fertilizer price ratio	1.31	–0.12	–0.44	–0.54
(% change)		(–9.09%)	(–33.33%)	(–41.18%)
Planted area ('000 ha)	19,261	–565	–2,072	–2,599
(% change)		(–2.93%)	(–10.76%)	(–13.29%)

Source: References in Table 1.
Notes: All base case values are for 1990. Real values are in constant 1980 pesos (MEX$). Elasticity measures are derived from Table 2a and

and contraction of planted area will also be determined by the effects of other liberalization policies on the comparative returns to competing economic activities on forest land. Although our analyses suggest that competition between livestock and agricultural activities for converted forest land may not be that significant, this may not necessarily hold for large and very rapid relative price movements. For example, the forestry sector in Mexico has generally been much less protected than agriculture, particularly maize. As a consequence, liberalization of the maize market could conceivably reduce significantly the comparative returns of maize cultivation to permanent forestry operations on the frontier, and this might reduce deforestation. On the other hand, cattle-raising and beef production are also protected in Mexico. As discussed below, as this sector has also been liberalized recently, the resulting impacts on the comparative returns to maize and cattle-raising are less certain. It could be that when maize prices are eventually liberalized the returns to maize relative to cattle production fall. As a result, the decline in planted area on the forest land may be at the expense of expansion in cattle-grazing. Because one conversion activity is essentially being replaced by another, the net effects on deforestation are more marginal.

Finally, if displacement of rural workers and subsistence farmers does occur as a result of liberalization, there may be a 'second-order' effect on deforestation. Some of the displaced workers and farmers may migrate to the frontier and convert additional forest land. Increased rural unemployment could also reduce real wages, which may make employment of labour for forest conversion and agricultural expansion much less expensive.

On balance, it may be better for Mexico to forgo instantaneous liberalization of its maize market in favour of a more gradual liberalization coupled with a large-scale programme of land improvements for existing rainfed agricultural land. The programme could be targeted to benefit particularly smallholders and subsistence producers. It is urgently necessary to include in this investment programme improved research and extension support that will reach those subsistence and low-income rainfed farmers in states with high rates of deforestation. Research and extension could reduce deforestation through the combination of improving yields on existing agricultural land and disseminating knowledge of land-saving rather than land-using farming systems and techniques. In addition, it is important to coordinate the liberalization policy for maize with liberalization of other sectors that also affect forest land use. Such a strategy would conform more closely to the 'ideal' maize policy for controlling excessive forest conversion than would a policy of more rapid liberalization on its own.

Fertilizer prices

Over the period 1989–91 Mexico reduced substantially its fertilizer subsidies. For example, country-level real prices for urea, ammonium nitrate and ammonium sulphate increased by 58 per cent, 74 per cent and 60 per cent respectively. As a result, the price of fertilizer at the railhead and thus to farmers has also risen sharply. Fertilizer prices in Mexico may rise further in the near future, if they follow the generally upward recent trends in world prices. If the policy of maintaining a constant fertilizer price across the country is also abandoned, then fertilizer costs would most certainly rise for farmers in the more remote areas.

In our model, fertilizer price changes also affect expansion of planted area through the maize/fertilizer price ratio variable. Thus an increase in fertilizer prices would have similar impacts to the fall in the price of maize discussed above, mainly by reducing the returns to agricultural, particularly crop, production.

Table 3b indicates the effects of an increase in fertilizer prices on the maize/fertilizer price ratio and thus planted area. For example, a 10 per cent increase in fertilizer prices would lead to an 11 per cent decrease in agricultural area planted. As noted above, fertilizer prices increased by around 50–70 per cent in real terms over the period 1989–91 as a result of liberalization. Our model indicates that, other things being equal, such substantial price changes may have a dramatic impact in reducing planted area and thus deforestation.[12]

[12] The simulated impacts on planted area for 50–70% reductions in fertilizer prices in Table 3b must be viewed as approximate 'orders of magnitude'. First, as noted above, applying elasticities calculated around the means of panel data and small (per unit) effects to much larger changes invariably increases inaccuracy. Second, such elasticities reflect 'instantaneous' changes. Although the fertilizer price rise in Mexico was fairly rapid, it did occur over a two-year period. Finally, liberalization in Mexico has been occurring across several sectors, which may make it difficult to distinguish the actual impacts on planted area of any single factor, such as rising fertilizer prices. Note that these same qualifications also apply to the simulations of beef prices and credit discussed below.

However, the actual implications of the recent rise in fertilizer prices on deforestation in Mexico are subject to the same considerations discussed above with regard to liberalization of the maize market. Much will depend on the impact of increased fertilizer prices on the comparative returns to maize and other frontier agriculture as opposed to other forest land use activities, particularly if liberalization brings large and very rapid relative price movements. In addition, as rising fertilizer prices may have reduced the returns to maize cultivation in the short term, any resulting loss of rural employment opportunities and fall in wages could lead to 'second-order' deforestation impacts through increased migration to the frontier and cheaper labour for conversion activities.

Finally, rising fertilizer prices also affect returns on both frontier and existing agricultural land. Although the more remote frontier areas have presumably experienced a greater increase because of increased transportation costs, the rapid and large rise in fertilizer prices will certainly have affected farmers on existing agricultural land as well. The burden may have fallen disproportionately on the poorer, mainly rainfed farmers, who may be discouraged from using fertilizer or reduce its use to sub-optimal levels. Any resulting impact on yields and productivity would also have the detrimental effect of encouraging deforestation, since the alternative to increasing production through yield increases is to expand cultivated area. For example, in an analysis across twenty-four Latin American countries, Southgate (1991) found that increased agricultural productivity and yield growth lead to less agricultural expansion. Thus, if in the short run the recent steep rise in fertilizer prices has drastically curtailed yield and productivity growth in Mexican agriculture, then the results may be counterproductive for controlling forest conversion.

In sum, there were clearly strong reasons for eliminating fertilizer subsidies in Mexico, on fiscal and efficiency grounds alone. Liberalization may also have had a secondary impact in reducing pressure for deforestation by reducing the incentives for agricultural land expansion, although it is clearly a blunt and far from ideal policy tool for this purpose. Our main concern is that the policy may become counterproductive, particularly in the short term, by discouraging fertilizer use by farmers, especially poorer households and those with smallholdings. Any resulting reduction in aggregate productivity and yield growth in Mexican agriculture would encourage agricultural expansion and thus deforestation. Such second-order effects could be mitigated by a national programme of land improvement investments to maintain and enhance productivity. Smallholders and subsistence farmers should be targeted as the main beneficiaries of the investment programme.

Beef prices

Cattle-raising and beef production are generally less protected in Mexico than the maize market. Nevertheless, there have been substantial subsidies, particularly in terms of credit and feed prices (see below). However, the GoM curtailed substantially its support for the producer price of beef over the 1989–91 period, although the actual impact on real prices is less well documented.

Our analysis shows that the recent liberalization of beef prices may influence the expansion of cattle numbers substantially by affecting the returns to cattle operations, as reflected in the beef/labour price ratio (see Table 4a). According to our simulations, a 10 per cent decrease in prices would cause beef cattle numbers to fall by around 4 per cent. If real beef prices have fallen by around 50–70 per cent, then there may be an even more dramatic effect on cattle numbers. As discussed in section 6, because there are limits on the amount of beef cattle held per farm, an increase in the number of farms and thus pasture area would be a likely outcome, unless there is sufficient investment in research and extension to improve productivity.

The analysis would therefore suggest that the recent reduction in beef prices may have reduced pressure on forest conversion to pasture. However, as discussed above, a crucial issue is how fast and to what degree liberalization has affected the comparative returns to cattle-raising as opposed to other activities at the forest frontier. To the extent that pasture area would decline at the expense of increased agricultural expansion, the net effects on forest conversion would be minimal.

Credit

The livestock sector in Mexico, particularly cattle-raising, has benefited in the past from subsidized loans. In more recent years, the overall level of loans to both agricultural and livestock activities has declined substantially, mainly as a result of increasing fiscal constraints on the GoM. However, the precise level of credit subsidy for cattle-raising is very difficult to determine.

Our analysis has shown that credit disbursements in general are an im-

Table 4. *Effects of changes in key policy variables on beef cattle*

a. Beef prices (nominal 1990 MEX$9,000/kg)

		Percentage change		
Effect on:	*Base case value*	*–10%*	*–50%*	*–70%*
Real beef prices (MEX$/kg)	26	–3	–13	–19
Beef cattle ('000 ha) (% change)	32,054	–1,345 (–4.20%)	–6,723 (–20.98%)	–9,413 (–20.37%)

b. Credit disbursements (nominal 1990 MEX$21,389 billion)

		Percentage change		
Effect on:	*Base case value*	*–10%*	*–50%*	*–70%*
Real credit disbursements (MEX$ billions)	120.13	–12.01	–60.07	–84.09
Beef cattle ('000 ha) (% change)	32.054	–437 (–1.36%)	–2,186 (–6.82%)	–3,061 (–9.55%)

Source: References in Table 1.
Notes: All base case values are for 1990. Real values are in constant 1980 pesos (MEX$). Elasticity measures are derived from Table 2b and Annex

portant determinant of cattle expansion (see Table 4b). For example, a 10 per cent decrease in loans would lead to a 1.4 per cent fall in the number of beef cattle. Thus the elimination of all credit subsidies for pasture formation and cattle-raising should have a significant influence on the conversion of forest land for pasture. Whether overall deforestation is reduced would depend on whether cattle-raising on the frontier is replaced by agricultural activities or by other land uses, such as permanent forestry operations or ecotourism, that would not depend on whole-scale conversion.

The elimination of subsidies for cattle-raising could be an important policy for controlling conversion of forest for pasture. Studies in other countries have indicated the extent to which subsidized cattle ranching has contributed to deforestation, particularly in areas of concentrated development. For example, in Brazil subsidies accounting for 54 per cent of livestock project development costs made uneconomic operations profitable in financial terms for the private investor (Repetto, 1988; Mahar and Schneider, 1994). In Mexico, removal of all subsidies from cattle-raising and maintaining the price of beef on a par with world prices are essential to ensuring that the beef cattle sector not only is efficient but also minimizes unnecessary deforestation.

8. NAFTA and deforestation in Mexico

To analyze the implications of NAFTA for Mexico's shift in development strategy, Hinojosa-Ojeda and Robinson (1991) developed a three-country (Mexico, US and the rest of the world) multisectoral, computable general equilibrium (CGE) model. In addition to examining the removal of tariff and non-tariff barriers to Mexican and US trade, the authors explored several different growth, investment and migration scenarios. By combining some of the results of the CGE model with those from the analysis of agricultural and cattle expansion in section 5, it is possible to obtain a broad indication of the deforestation impacts of Mexico's economic transition to liberalization. Tables 5 and 6 summarize the implications for planted area and cattle numbers of the seven different NAFTA scenarios.[13]

In general, the pursuit of an open development strategy (scenarios 4–6) combining high economic growth and liberalization appears to mitigate agricultural area and cattle expansion more than reliance on liberalization alone (scenarios 1–3). In scenarios 4–6, the impact of an increased labour force in stimulating growth in planted area and cattle numbers seems to be offset by higher real income per capita and rural wages in reducing agricultural and cattle expansion. In the liberalization and pro-competitive scenarios 1–3, the results are more mixed and uncertain. However, if Mexico undergoes a long transition to sustained economic growth and is subject to substantial return migration to rural areas (scenario 7), then the positive inducement to forest conversion from increases in the labour force and falling rural wages may outweigh the incentives to reduce agricultural and

[13] Table 5 assumes that increases in the labour force will have the same effect on planted area and cattle numbers as the explanatory variable for population in our analysis. In Mexico, the labour force, as defined by all individuals aged 15–64, comprises approximately 60 per cent of the total population.

Table 5. *Net deforestation effects of changes in labour force*

Scenario	*% change in labour force**	*% change in planted area†*	*% change in cattle numbers†*
1. Tariff removal	−0.1	−0.03	−0.01
2. Liberalization	0.3	0.09	0.03
3. Pro-competitive	1.0	0.29	0.11
4. Mexican growth	0.1	0.03	0.01
5. Mex. transition	0.1	0.03	0.01
6. Growth & mig.	1.4	0.40	0.15
7. Trans. & mig.	5.0	1.44	0.53

Source: * Percentage change over 1988 base case values, from Hinojosa-Ojeda and Robinson (1991).
† See Table 2.
Notes:
1. Remove all official tariffs.
2. Tariff removal plus removal of all quantity restrictions on imports.
3. Liberalization plus capital reallocation due to lower distortions in domestic capital markets in the USA and Mexico in light manufacturing, intermediates and consumer durables.
4. Pro-competitive liberalization plus increased aggregate capital stock in Mexico (7.6%). No return migration.
5. Modified Mexican growth scenario, with half the increase in aggregate capital stock (3.8%) plus increased foreign borrowing by Mexico. No return migration.
6. Mexican growth scenario plus return migration to Mexico.
7. Modified Mexican growth scenario plus return migration to Mexico.

cattle expansion due to increasing real GDP per capita. Thus the ability of the Mexican economy and rural labour market to adapt to an open development strategy could be a key determinant of the overall impacts on deforestation.

In sum, if Mexico adopts an open development strategy of joining NAFTA while simultaneously pursuing vigorous economic development at home, then the increasing returns and output in agricultural and livestock production could translate into additional forest conversion. However, these impacts may be mitigated if the open development strategy is combined with the more specific agricultural and livestock sector policy reforms discussed in the previous section.

More detailed partial equilibrium analysis of the implications of NAFTA for the maize sub-sector in Mexico has been conducted (Levy and van Wijnbergen 1992a, b). However, this analysis also does not explicitly address the impacts on forest land conversion and degradation. Some possible effects of the different scenarios can nevertheless be inferred, which generally support the conclusions from our own policy analysis of agricultural expansion discussed in section 7.

Maize accounts for over half the crop area harvested in Mexico and employs approximately one third of rural workers (World Bank, 1989). In 1989, out of a total production of 12.8 million tons, 8.8 million tons were produced by rainfed farmers, and rural own consumption accounted for 3.6 million tons. Thus, out of the estimated 2,250,000 maize producers in

Table 6. *Net deforestation effects on changes in real GDP*

Scenario	*% change in real GDP**	*% change in real GDP per capita†*	*% change in cattle numbers‡*
1. Tariff removal	0.1	−1.7	−0.16
2. Liberalization	0.3	−1.5	−0.14
3. Pro-competitive	1.2	−0.6	−0.06
4. Mexican growth	6.4	4.6	0.43
5. Mex. transition	3.0	1.2	0.11
6. Growth & mig.	6.8	5.0	0.46
7. Trans. & mig.	4.5	2.7	0.25

Source: * Percentage change over 1988 base case values, from Hinojosa-Ojeda and Robinson (1991).
† Assumes annual average population growth of 1.8% over 1989–2000.
‡ From Table 2.
Notes:
1. Remove all official tariffs.
2. Tariff removal plus removal of all quantity restrictions on imports.
3. Liberalization plus capital reallocation due to lower distortions in domestic capital markets in the USA and Mexico in light manufacturing, intermediates and consumer durables.
4. Pro-competitive liberalization plus increased aggregate capital stock in Mexico (7.6%). No return migration.
5. Modified Mexican growth scenario, with half the increase in aggregate capital stock (3.8%) plus increased foreign borrowing by Mexico. No return migration.
6. Mexican growth scenario plus return migration to Mexico.
7. Modified Mexican growth scenario plus return migration to Mexico.

Mexico, at most 15 per cent of all producers are net sellers, comprising 250,000 large-scale producers on irrigated land and 80,000 rainfed farmers. This leaves approximately, 1,920,000 subsistence maize farmers on rainfed lands (Levy and van Wijnbergen, 1992a).

To encourage domestic production, maize rural producer prices were heavily subsidized in Mexico. In 1989, the subsidy amounted to US$72.8 per ton, or 54 per cent of the world price (Levy and van Wijnbergen, 1992a). The net producer subsidy after rural consumption amounted to US$291.2 million, of which US$109.2 million (38 per cent) went to producers on irrigated lands and US$182 million (62 per cent) to rainfed farmers who were net sellers. In addition, subsidies to (mainly) urban consumers ensured that the consumer price of maize was well below the world price. This consumption subsidy amounted to US$50.37 per ton (37 per cent), or a total subsidy of US$327.40 million.

Levy and van Wijnbergen (1992a) conduct a comparative static analysis of the effects of complete liberalization of the maize market through Mexico joining NAFTA. They estimate that a move to free trade in maize would reduce the rural price of maize by approximately 50 per cent. The result would be a reduction in maize output from irrigated land of 0.97 million tons (from 1.5 million to 0.53 million tons) and of 4.5 million tons from rainfed land (from 8.8 million to 4.3 million tons). Approximately

3.21 million hectares of rainfed land and 0.32 million hectares of irrigated land would be taken out of maize production. As irrigated land would be switched to non-maize production (e.g. vegetables) that is likely to be more labour-intensive, there may be a slight net employment gain. However, approximately half of the released rainfed land would be converted to pasture for grazing, with the remainder devoted to other grain crops or fallow. Unemployment on rainfed land may therefore increase by 145,000 workers, putting downward pressure on the rural wage rate.

On the positive side, the 3.75 million rural and mainly landless workers in Mexico would benefit as consumers from lower rural prices for maize. The 1.92 million subsistence producers on rainfed lands would gain or lose little. Levy and van Wijnbergen (1992a) estimate that the overall welfare benefits to the Mexican economy of moving to free trade would be US$154 million per year, with the reduction in rural price distortions accounting for US$122 million per year.

The implications of the scenario for deforestation in Mexico depend on a number of important factors. The fall in the rural producer price of maize ought to put less pressure on the demand for agricultural land, and thus for additional forest conversion. Section 7 discussed in some detail the implications of a large fall in maize producer prices as a result of liberalization. For example, in Table 3 a 10 per cent fall in maize prices would lead to a 3.2 per cent decrease in planted area; whereas the 50 per cent fall predicted by Levy and van Wijnbergen (1992a) would lead to a 16.1 per cent decrease, although as discussed in section 7 any such large changes may not be realistic and should be viewed with caution. Nevertheless, one would expect a major reduction in the producer price of maize from liberalization to lead to a substantial contraction in production and thus planted area.

The key issue is what happens to the land currently under maize that is taken out of production. If, as Levy and van Wijnbergen (1992a) assume, one half of the released rainfed land is converted to pasture (1.6 million hectares), then the demand for additional forest land for pasture may also lessen, depending of course on the comparative returns of released maize and forest land for livestock grazing. On the other hand, if the 145,000 rural workers released by free trade in maize do not migrate to employment opportunities in the urban areas or the USA, then they may instead move to the forest frontier in Mexico as subsistence farmers.[14] In the extreme case, this could lead to the conversion of an additional 362,500 hectares of forest land—a more than 50 per cent increase in the current annual rate of deforestation of 668,000 hectares per year.[15] As discussed

[14] However, in the future there may be limitations on large-scale migration to forest areas as most of this land is allocated to *ejidos*, which now have legal ownership rights. For further discussion, see Barbier *et al.* (1993).

[15] The extreme scenario for deforestation assumes that the 145,000 displaced rural workers become subsistence maize producers on the frontier with an average holding size of 2.5 hectares. This scenario is clearly unlikely. However, it is worth noting that, assuming the same average holding, additional forest conversion of 100,000 hectares in Mexico would require only 40,000 displaced rural workers to move onto forest land.

above and in section 7, these 'second-order' deforestation effects through reduced rural employment opportunities could be significant and even outweigh the direct effects of the initial contraction in planted area.

A further partial equilibrium analysis of the impact of NAFTA on Mexico's maize sub-sector was also conducted (Levy and van Wijnbergen, 1992b). This more detailed analysis involved several scenarios concerning different intertemporal assumptions and effects. The implications for the value of rainfed and irrigated land under maize production were examined, along with the welfare and efficiency impacts. These effects are summarized in Tables 7 and 8.

Instantaneous or even gradual liberalization on its own yields large efficiency gains for the Mexican economy, but the consequence is a large fall in land values for rainfed land to less than one quarter of those for irrigated land (see Table 7). Thus subsistence farmers, rainfed farmers who are net sellers, and landless rural workers would be made worse off by the contraction in maize production from rainfed land, the loss of its capital value and the subsequent displacement of rural workers. Although subsistence farmers benefit from lower consumer prices, they are doubly affected by the loss in value of their rainfed land and in employment opportunities as day labourers. The major concern is that lack of employment and income opportunities will induce rural workers and subsistence farm-

Table 7. *Effects of NAFTA on land values and holdings under maize, Mexico (million pesos per ha, 1989 values)*

Scenario	*Rainfed land*	*Irrigated land*	*Land holdings of subsistence and rainfed farmers*	*Land holdings of irrigated farmers*
Base case	12.065	40.169	12.065	40.169
Case 1	9.231	40.800	9.231	40.800
Case 2	9.443	40.725	9.443	40.725
Case 3	9.180	40.668	11.499	40.668
Case 4	9.390	40.597	11.703	40.597
Case 5	9.608	42.175	12.030	42.175
Case 6	9.726	42.137	12.141	42.137

Source: Levy and van Wijnbergen (1992b).
Notes:

Base case	1989 values as the reference case.
Case 1	Instantaneous liberalization of all maize prices in Mexico.
Case 2	Gradual liberalization, with maize prices in Mexico moving to world prices over next 5 years.
Case 3	As case 1, but 1.1 million ha of rainfed land are transformed to irrigation over next 5 years.
Case 4	As case 2, but 1.1 million ha of rainfed land are transformed to irrigation over next 5 years.
Case 5	As case 4, but US fruit and vegetable market is liberalized over next 5 years.
Case 6	US fruit and vegetable market is liberalized and 1.1 million ha of rainfed land are transformed to irrigation over next 5 years, but maize price liberalization in Mexico begins 1 year after irrigation programme starts.

Table 8. *Welfare and efficiency effects of maize liberalization, Mexico*

Scenario	*Subsistence farmer*	*Landless rural worker*	*Rainfed farmer*	*Irrigated farmer*	*Efficiency gains*
Case 1	0.967	0.984	0.943	1.028	42.44
Case 2	0.971	0.985	0.949	1.024	23.17
Case 3	1.007	0.993	0.996	1.019	51.96
Case 4	1.011	0.995	1.001	1.015	49.57
Case 5	1.013	1.000	1.000	1.028	44.81
Case 6	1.015	1.001	1.003	1.025	43.18

Source: Levy and van Wijnbergen (1992b).
Notes:

Base case	1989 values as the reference case.
Case 1	Instantaneous liberalization of all maize prices in Mexico.
Case 2	Gradual liberalization, with maize prices in Mexico moving to world prices over next 5 years.
Case 3	As case 1, but 1.1 million ha of rainfed land are transformed to irrigation over next 5 years.
Case 4	As case 2, but 1.1 million ha of rainfed land are transformed to irrigation over next 5 years.
Case 5	As case 4, but US fruit and vegetable market is liberalized over next 5 years.
Case 6	US fruit and vegetable market is liberalized and 1.1 million ha of rainfed land are transformed to irrigation over next 5 years, but maize price liberalization in Mexico begins 1 year after irrigation programme starts.
Welfare effects	Measured as a percentage of the base case.
Efficiency gains	Measured in 1989 US$ billion. In 1989, Mexico's GDP was US$ 207 billion.

ers to migrate towards frontier forest areas, or to convert remaining forest land available to them locally. These 'second-order' effects could outweigh the initial impacts of, say, a reduction in maize producer prices on planted agricultural area.

In comparison, a programme of investment in land improvements to increase the productivity of rainfed land could potentially mitigate the negative distributional implications of NAFTA on the maize sub-sector. Such a programme could involve investments not only in irrigation infrastructure for 1.1 million hectares of rainfed land but also in drainage, land levelling, ditch-clearing and soil conservation. The distributional impacts of maize liberalization in Mexico are particularly reduced if the land improvement programme is combined with greater access for Mexican farmers to the US fruit and vegetable market, and possibly if land improvement investments are initiated before liberalization. Consequently, expansion of rural farm employment opportunities on existing agricultural land, or off-farm employment opportunities generally, could be an important factor in mitigating deforestation. This suggests that a land improvement investment programme for existing rainfed farmers, particularly in states and regions prone to high deforestation rates, could provide indirect incentives for controlling deforestation by increasing the demand for rural labour.

The results of the analysis lead Levy and van Wijnbergen to conclude that Mexico would do better to forgo instantaneous liberalization of its maize market in favour of a more gradual liberalization coupled with a large-scale programme of investment in land improvements for rainfed agriculture. This conforms with our own conclusions in section 7 from the policy analysis of the effects of maize and fertilizer prices on agricultural expansion. By increasing the value and returns of rainfed land through irrigation, the land investment programme would also enhance farmers' access to credit and encourage them to cultivate high value crops other than maize. Moreover, if targeted to farmers on existing rainfed land, the programme would possibly make it more attractive for farmers to bring their idle land into production, as depicted in Figure 1. That is, increasing the returns to existing rainfed farmland and transforming it into irrigation could reduce the incentives for farmers to 'abandon' their existing land to convert additional forest land. As irrigated land in Mexico is about 2.4 times more labour-intensive than rainfed land, the land improvement programme should also create a permanent demand for rural labour (Levy and van Wijnbergen, 1992b). Thus the possibility of displaced rural workers and subsistence farmers migrating to the forest frontier as a result of maize liberalization might be substantially reduced and possibly reversed.

Finally, it is worth commenting that although we have attempted to show the linkages between our analytical results and related general equilibrium studies of the impacts of NAFTA on the Mexican economy, the ability to use a partial analysis to predict economy-wide changes will clearly be limited. In particular, as the discussion in this section demonstrates, many crucial 'second-order' deforestation effects are beyond the predictive power of our analyses of the demand for agricultural land and livestock numbers. On the other hand, current CGE models that attempt to simulate the impacts of NAFTA on the Mexican economy usually exclude any likely deforestation effects.

The exception is a recent model by Boyd (1994). However, due to necessary aggregation, in this model deforestation is simulated by changes in fixed land demand and supply relationships in the overall forestry, livestock and agricultural sectors. Thus, as the author admits, there are limitations on the model's ability to forecast accurately deforestation effects. The results of the analysis suggest that agricultural and livestock production should be expected to increase as a result of NAFTA reforms, and there is likely to be an influx of unemployed workers displaced from industry (cross-border migration is not included in the analysis). The demand for land should increase and its price rise. The author suggests that these effects are likely to increase deforestation unless trade liberalization is implemented in conjunction with land reform. The goal of such land reform would be to absorb displaced workers onto improved existing agricultural and livestock land to prevent them from opening up frontier forest land.

9. Conclusions

Previous studies of deforestation suggest that agricultural land expansion and pasture formation are two major causes of forest conversion. Evidence presented in this paper indicates that this is also the case for Mexico. The factors determining increases in the land under agricultural production and pasture would also be the underlying causes of deforestation.

However, unlike in some statistical analyses of deforestation, our analysis was unable to examine the relationships influencing deforestation directly. Instead, a more indirect approach was taken of using panel analyses to estimate relationships for agricultural planted area and beef cattle at the state level over the 1970–85 period. We believe that such an approach gives a strong indication of the factors underlying forest conversion, as increases in both land under agricultural production and beef cattle numbers seem to be correlated with loss of forest area.

In the case of increased planted area, increasing the relative returns to maize production as reflected in the maize price ratio leads to further pressure on the forest. Rising populations at the state level also have an impact on forest conversion. In the case of beef cattle numbers, the most significant influence appears to be the returns to cattle operations, as reflected in the price of beef. Increasing credit disbursements, population levels and, to a lesser extent, per capita income are also important factors underlying forest conversion for cattle-raising. Surprisingly, road density was not significant in either analysis. In addition, livestock prices did not influence the demand for agricultural land nor did maize price affect the demand for cattle. This suggests that, over the 1970–85 period at least, livestock production and agricultural expansion may not be competing for land on the forest frontier in states across Mexico. Nevertheless, as the overall demand for land can be expected to increase, especially with rising population, the result may be greater competition between livestock and agricultural activities for frontier land.

The agricultural land and cattle numbers analyses provide some indication of the key policy and socio-economic variables that may be influencing deforestation in Mexico. To utilize these results in policy analysis, we concentrated on the role of maize and fertilizer prices in affecting the returns to agriculture and thus the expansion of planted area; beef prices affecting the returns to cattle-raising and thus the expansion of cattle numbers; and credit disbursement affecting cattle operations.

Our general conclusion is that recent liberalization of the fertilizer market, which may soon be followed by removal of maize price subsidies, may have reduced incentives for expanding planted area and forest conversion. However, the failure to take into account the employment implications of 'fast-track' liberalization of the maize and fertilizer markets could translate into 'second-order' deforestation effects. The major concern is that lack of employment and income opportunities will induce rural workers and subsistence farmers to migrate towards frontier forest areas or convert remaining forest land available to them. These 'second-order' effects could outweigh the initial impacts of the reduction in the returns to maize production on planted agricultural area. Moreover, a rapid fall in the returns to maize cultivation could have tremendous welfare implications for low-income and subsistence rainfed farmers.

These second-order effects on deforestation may be counteracted somewhat if liberalization of the fertilizer and particularly maize markets is coupled with a large-scale programme for land improvements for existing rainfed agricultural land. Fiscal savings from the removal of subsidies could be redirected to finance these investments. The programme could be targeted to benefit particularly smallholders or subsistence producers. Such a programme has the additional benefit of providing alternative employment and income opportunities for landless and near-landless workers, thus reducing their incentive to encroach on forest land.

To improve its effectiveness in reducing deforestation, an investment programme in land improvement should include research and extension support for subsistence and low-income rainfed farmers in states with high rates of deforestation. Research and extension could reduce deforestation by both improving yields on existing agricultural land and disseminating knowledge of land-saving rather than land-using farming systems and techniques. In addition, it is important to coordinate the liberalization policy for maize with liberalization of other sectors that also affect forest land use. Such a strategy would conform more closely to the 'ideal' maize policy for controlling excessive forest conversion than a policy of more rapid liberalization on its own.

In the case of the cattle market, liberalization of beef prices may also reduce the pressure of pasture expansion on the forest. A crucial issue determining this outcome is still the comparative returns to cattle ranching as opposed to other frontier activities. Another factor is the extent to which the costs of production are still being subsidized through credit loans and other input subsidies. Thus a more important policy initiative would be the removal of these subsidies. In particular, the elimination of credit subsidies for cattle-raising ought to make this activity more efficient and reduce perverse incentives for deforestation.

The implications of NAFTA for deforestation in Mexico are difficult to discern. With the exception of a recent study by Boyd (1994) the impacts on forest conversion and degradation are generally ignored in CGE models of NAFTA's impacts on Mexico. Nevertheless, by combining the results from selected studies with those from our policy analysis, it is possible to identify some important relationships, which are to a large extent supported by the general results obtained by Boyd (1994).

The available evidence suggests that if NAFTA is used to complement additional internal economic reforms within Mexico, then this 'open development' strategy would lead to increased output and returns to Mexican agriculture. If forest conversion is to be minimized, then it is imperative that the more specific sectoral policy reforms discussed above, coupled with legal reforms, are implemented. First, pricing and other policies in the agricultural and livestock sector that artificially 'subsidize' the returns to conversion activities on forest land or the costs of conversion need to be reformed. Second, land tenure, forestry and environmental laws also need to be tightened to reduce the incentives for rent-seeking behaviour on the frontier or to improve the 'internalization' of any environmental impacts associated with forest conversion and degradation (Barbier *et al.*, 1993). Finally, specific investments for the agricultural and livestock sectors for improving productivity, infrastructure and research and extension must be targeted towards bringing existing idle arable land into production as well as improving productivity on land already under cultivation.

The specific example of maize liberalization illustrates the approach needed. Combining gradual liberalization with a major land improvement investment programme for existing rainfed agricultural land reduces the incentives for farmers to 'abandon' their existing land to convert additional forest land. However, the success of this programme in mitigating deforestation would depend critically on its being targeted to existing rainfed land and not providing perverse incentives for farmers in frontier areas to convert forest areas rapidly to maize production in order to qualify for the investment programme. The programme would also create additional permanent rural demand, thus reducing any pressure on forest resources by displaced rural workers or subsistence farmers extending their planted area.

This paper began by examining other studies of deforestation that are relevant to the factors influencing forest conversion in Mexico. We hope that the results of this policy analysis are in turn relevant to economic studies of the causes of deforestation in other developing countries. In particular, we believe that examining the extent to which changes in government policies are likely to influence deforestation through affecting the comparative economic returns to different conversion activities on forest land as well as the comparative returns to economic activities on existing as opposed to frontier land is important not only for Mexico and Latin America but for all tropical forest countries. As indicated, there were many limitations on our ability to conduct a full analysis of this problem. We hope that further studies will improve upon our policy analysis both for Mexico and for other countries.

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APPENDIX

Description of the models for agricultural land and beef numbers

Given limitations on the data for deforestation in Mexico, planted agricultural area and beef cattle numbers were used as proxies for deforestation. These two indicators were then regressed on key policy and socio-economic variables to determine the significant factors in the deforestation process. The following describes briefly the data and analysis used in the two models.

Demand for agricultural land

The panel analysis of longitudinal data for planted agricultural area was conducted across the thirty-one states of Mexico plus the *Distrito Federal* (Federal District), over the 1970, 1980 and 1985 time periods. Several explanatory variables were examined, including real guaranteed maize prices, real fertilizer prices, income per capita, population levels, real rural wages and road density. In addition, real livestock prices were included to determine the extent to which this variable influences the agricultural land expansion. Details of the relevant variables and source are given in Table 1.

In the original panel analysis of the demand for agricultural land, ordinary least-squares (OLS) regressions were employed (Barbier *et al.*, 1993). However, OLS provides consistent and efficient estimators of the coefficients of the explanatory variables only if any individual effects are constant over time and across all individual cross-sectional units (i.e. the Mexican states including the Federal District). This is a fairly restrictive assumption that generally does not hold for panel analysis of longitudinal data (Hsiao, 1986; Greene, 1993; Baltagi, 1995). Instead, a common procedure is to test for the presence of individual effects in an OLS model in comparison to fixed- and random-effects versions of a (one-way) error component model. We used a least-squares dummy variable (LSDV) regression for the fixed-effects error component model, and a feasible generalized least-squares (FGLS) estimation for the random-effects version.

The LSDV approach requires the inclusion of dummy variables for each unit in the regression. We utilized the FGLS procedure suggested by Greene (1993), which follows the general approach adverted for random-effects models (Hsiao, 1986; Baltagi, 1995). This is a two-step procedure that involves deriving residual variance estimators from between-units (unit means) and within-units (LSDV) regressions, and using these estimators to derive θ for the following FGLS regression:

$$y_{it} - \theta\bar{y}_i = \alpha(1-\theta) + \beta'[x_{it} - \theta x_i] + u_{it} - \theta\bar{u} \qquad i = 1,...,N;\ t = 1,...,T \quad \text{(A1)}$$

where i denotes the individual cross-sectional units (i.e. the states), t denotes time, α is a scalar, and β is the $K \times 1$ vector of coefficients on the K explanatory variables. It follows that y_{it}, x_{it} and u_{it} are the *it*th observations on the dependent variable, the K explanatory variables and the error term respectively, with $\bar{y}_i$, $\bar{x}_i$ and $\bar{u}$ being the respective unit means.[16]

Table A1 depicts the OLS, LSDV and FGLS regression results for planted agricultural area. Table A1a depicts the regression results without real

Table A1. *Regression results for agricultural area planted (MAAP)*

a. Without real livestock prices (N = 32, T = 3, K = 4)

	MGMFP	*MP*	*MRD*	*MYC*
OLS	342.18	0.000087†	−66.385*	−0.02073†
	(1.83)	(4.08)	(2.14)	(3.10)
LSDV	131.58	0.000070*	−0.472	0.00533
	(1.48)	(2.11)	(0.02)	(1.08)
FGLS	167.49*	0.000077†	−13.676	0.00087
	(1.86)	(3.13)	(0.52)	(0.18)

$\theta = 0.733226$.
$F_{N-1,NT-N-K} = 14.66$†.
Breusch–Pagan $LM_1(\chi_1^2) = 48.77$†.
Hausman $(\chi_K^2) = 10.88$*.
* Statistic significant at 5% level.
† Statistic significant at 1% level.

b. With real livestock prices (N = 32, T = 3, K = 5)

	MGMFP	*MLP*	*MP*	*MRD*	*MYC*
OLS	575.24†	−86.727	0.000085†	−82.271†	−0.02244*
	(2.53)	(1.76)	(4.06)	(2.58)	(2.35)
LSDV	112.13	6.866	0.0000740*	−0.258	0.00548
	(0.93)	(0.24)	(2.01)	(0.01)	(1.09)
FGLS	184.04	−4.543	0.000077†	−15.583	0.00029
	(1.86)	(0.16)	(3.00)	(0.58)	(0.06)

$\theta = 0.717463$.
$F_{N-1,NT-N-K} = 13.88$†.
Breusch–Pagan $LM_1(\chi_1^2) = 42.65$†.
Hausman $(\chi_K^2) = 29.57$†.
* Statistic significant at 5% level.
† Statistic significant at 1% level.
Notes: OLS = ordinary least squares; LSDV = least squares dummy variable; FGLS = feasible generalized least squares. For variable definitions, see Table 1.

[16] From Greene (1993), $\theta = 1 - [(RVE_w)/(T * RVE_b)]^{1/2}$, where RVE_w is the residual variance estimator based on the within-units (LSDV) estimation and RVE_b is the residual variance estimator based on the between-units (unit means) estimation.

livestock prices included as an explanatory variable; Table A1b shows the results with livestock prices. The coefficients of the relevant explanatory variables are depicted, with the absolute values of the t-test statistics indicated in parentheses below each coefficient.

An F-test for the null hypothesis of zero individual effects across states was performed. The hypothesis is soundly rejected in both versions of the regression, which suggests that the fixed-effects (LSDV) estimator is preferred to the OLS estimator. The Breusch–Pagan LM_1 test is also performed for the null hypothesis of zero random effects, which is distributed as χ_1^2. This null hypothesis is also rejected for both regressions, which suggests that the random-effects (FGLS) estimator is preferred to the OLS estimator. Finally, a Hausman test was performed with χ_K^2 degrees of freedom for the null hypothesis of no differences between the FGLS random-effects and the LSDV fixed-effects estimators. The statistic was significant at the 5% level for the regression without livestock prices and at the 1% level for the regression with livestock prices. Thus in both versions the null hypothesis can be rejected. The value of θ for the FGLS regressions, the F-test statistic, the Breusch–Pagan LM_1 statistic and the Hausman χ_K^2 statistic are indicated in Table A1.

The results of these diagnostic test results suggest that FGLS is the preferred estimator in both versions of the regression. In Table A1a the t-tests for the FGLS regression for planted agricultural area show that the only significant explanatory variables are relative maize/fertilizer prices and population. Real income per capita and road density are not significant. In Table A1b, t-tests for the FGLS regression indicate that only population is fully significant, as the two-tailed t-statistic for the coefficient on relative maize/fertilizer prices is no longer significant at the 5% level. The other variables in the regression, including real livestock prices, are highly insignificant.[17] These results imply that the hypothesis that livestock prices should influence planted agricultural area is rejected by the model and that, of the two versions of the model, FGLS without livestock prices in Table A1a is the preferred estimator. Further discussion of the results of the model can be found in section 4.

Demand for beef cattle

The panel analysis of longitudinal data for beef cattle numbers (i.e. livestock head) was also conducted across the thirty-one states of Mexico plus the Federal District, over the 1970, 1980 and 1985 time periods. Several explanatory variables were examined, including real beef prices, income per capita, population levels, real rural wages, road density and real credit disbursement. Real guaranteed maize prices were also included to determine the extent to which the expansion in beef numbers is explained by this

[17] Both versions of the model were also run with real rural wages included, but this variable also proved to be insignificant. Moreover, its inclusion did not alter substantially the coefficients of the other variables nor did it affect their significance. Both an F-test and log-likelihood test on the null hypothesis that rural wages is a redundant variable were performed, but the tests were highly insignificant. Thus we omitted rural wages in both versions of the model in Table A1.

variable. Details of the relevant variables and sources are given in Table 1. The same two-step procedure for panel analysis of longitudinal data described above for planted agricultural area was also employed to derive the estimators of livestock head.

Table A2 depicts the OLS, LSDV and FGLS regression results for cattle numbers. Table A2a depicts the regression results without real maize prices included as an explanatory variable; Table A2b shows the results with maize prices. As before, the coefficients of the relevant explanatory variables are depicted, with the absolute values of the t-test statistics indicated in parentheses below each coefficient. The value of θ for the FGLS regressions, the F-test statistic, the Breusch–Pagan LM_1 statistic and the Hausman χ_K^2 statistics are also indicated.

An F-test for the null hypothesis of zero individual effects across states was performed. The hypothesis is again soundly rejected in both versions of the regression, which suggests that the fixed-effects (LSDV) estimator is

Table A2. *Regression results for livestock head (MLH)*

a. Without real guaranteed maize prices (N = 32, T = 3, K = 5)

	MLP	*MP*	*MRD*	*MC*	*MYC*
OLS	–26.712	0.000111†	–106.504*	0.9958†	–0.01303
	(0.40)	(3.12)	(2.17)	(6.23)	(1.19)
LSDV	41.328†	0.000037	–12.941	0.3573†	0.00923†
	(2.67)	(1.42)	(0.62)	(7.37)	(2.59)
FGLS	43.425†	0.000051*	–24.315	0.3765†	0.00865*
	(2.67)	(3.13)	(1.14)	(7.41)	(2.29)

θ = 0.886253.
$F_{N-1,NT-N-K}$ = 82.05†.
Breusch–Pagan $LM_1(\chi_1^2)$ = 884.22†.
Hausman (χ_K^2) = 1.74.
* Statistic significant at 5% level.
† Statistic significant at 1% level.

b. With real guaranteed maize prices (N = 32, T = 3, K = 6)

	MLP	*MGMP*	*MP*	*MRD*	*MC*	*MYC*
OLS	–79.948	–0.9132	0.000114†	–108.672*	0.9803†	–0.01292
	(0.84)	(0.79)	(3.18)	(2.20)	(6.07)	(1.18)
LSDV	18.005	–0.2776	0.000038	–5.086	0.3427†	0.00956†
	(0.61)	(0.92)	(1.43)	(0.23)	(6.72)	(2.65)
FGLS	24.620	–0.2266	0.000052*	–18.474	0.3652†	0.00888*
	(0.79)	(0.71)	(2.02)	(0.81)	(6.84)	(2.34)

θ = 0.886106.
$F_{N-1,NT-N-K}$ = 81.29†.
Breusch–Pagan $LM_1(\chi_1^2)$ = 855.99†.
Hausman (χ_K^2) = 2.10.
* Statistic significant at 5% level.
† Statistic significant at 1% level.
Notes: OLS = ordinary least squares; LSDV = least squares dummy variables; FGLS = feasible generalized least squares. For variable definition see Table 1.

preferred to the OLS estimator. The Breusch–Pagan LM_1 test is also performed for the null hypothesis of zero random effects, which is distributed as χ_1^2. This null hypothesis is also rejected for both regressions, which suggests that the random effect (FGLS) estimator is preferred to the OLS estimator. Finally, a Hausman test was performed with χ_K^2 degrees of freedom for the null hypothesis of no difference between the FGLS random-effects and the LSDV fixed-effects estimators. However, for regressions both with and without maize prices this statistic proved not to be significant at the 5% level. Thus in both versions of the regression for livestock numbers the null hypothesis of no difference between the FGLS and LSDV estimators can be rejected. Nevertheless, the highly significant Breusch–Pagan statistics suggest the presence of random effects; consequently, FGLS is still the preferred estimator in both versions of the regression.

In Table A2a the t-tests for the FGLS regression for livestock head show that livestock prices, population, credit and income per capita are all significant. Road density is the only variable that is not significant. In Table A2b, t-tests for the FGLS regression indicate that only population, credit and income per capita are significant. Real livestock and maize prices join road density in being highly insignificant.[18] These results imply that the hypothesis that maize prices should influence demand for beef cattle is rejected by the model and that, of the two versions of the model, FGLS without maize prices in Table A2a is the preferred estimator. Further discussions of the results of the model can be found in section 4.

[18] Both versions of the model were also run with real rural wages included, but incorporating this variable appeared to lead to severe problems of multicollinearity. In particular, rural wages seemed highly correlated with income per capita and livestock prices. Thus the inclusion of rural wages reduced substantially the significance of the latter two variables and distorted the regression generally. We therefore omitted rural wages in both versions of the model in Table A2.